

**FINAL**

**Intrinsic Remediation  
Engineering Evaluation/Cost Analysis Addendum  
for UST Site 870**



**Hill Air Force Base  
Ogden, Utah**

**Prepared For**

**Air Force Center for Environmental Excellence  
Technology Transfer Division  
Brooks Air Force Base, Texas  
San Antonio, Texas**

**and**

**Hill Air Force Base  
Ogden, Utah**

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**September 1999**

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08 September 1999

Mr. Jerry Hansen  
Technical Program Manager  
AFCEE/ERT  
3207 North Road, Bldg. 532  
Brooks AFB, TX 78235-5363

Subject: Submittal of the Final Intrinsic Remediation Engineering Evaluation/Cost Analysis Addendum for UST Site 870, Hill AFB, Utah (Contract F41624-92-D-8036-0025)

Dear Mr. Hansen:

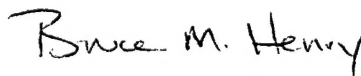
Enclosed please find two copies of the September 1999 Final Intrinsic Remediation Engineering Evaluation/Cost Analysis Addendum for UST Site 870, Hill AFB, Utah. This report was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) and Hill AFB.

The intent of the EE/CA Addendum was to determine the role of natural attenuation in remediating fuel contamination in groundwater at Site 870. The draft EE/CA Addendum was submitted to AFCEE in April 1999. Comments on the draft EE/CA Addendum were received from AFCEE as reviewed by Daniel W. Kraft of Waste Policy Institute (WPI), dated July 26, 1999. Responses to these comments were prepared by Parsons ES and are attached to this letter.

If you have any questions or require additional information, please call me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.



Bruce M. Henry, P.G.  
Project Manager

Enclosures

cc: Kevin Bourne - Hill AFB  
Don Kampbell - USEPA NRMRL



**Responses to AFCEE Comments on the  
Draft Intrinsic Remediation Engineering Evaluation/Cost Analysis Addendum  
for UST Site 870, Hill AFB, Utah  
July 26, 1999**

Comment 1) The report is well organized and easy to follow. Site conditions for the three monitoring events are concisely summarized and displayed for comparison.

Parsons ES Response: *Comment noted.*

Comment 2) The document is generally complete. Section 2.0 states that groundwater samples were analyzed for methyl tert-butyl ether (MTBE); however, MTBE analytical results are not presented or discussed in the report.

Parsons ES Response: *MTBE, a fuel additive, was analyzed for the first time in groundwater samples collected at the site in September 1998. Low levels of MTBE (less than 5 micrograms per liter) were detected in monitoring wells EPA-82D, EPA-82I, LTM-6, and LTM-8. MTBE appears to be associated with the BTEX plume. However, because of the low detected concentrations of MTBE, this compound is not a regulatory concern at Site 870. Table 3 will be revised to include results of the MTBE analyses.*

Comment 3a) The dissolved-phase plume, approximately 1,950 feet long and 800 feet wide, is significantly larger than most fuel hydrocarbon plumes. Six sampling locations for a plume of this size is only marginally adequate for determining plume concentrations, background conditions, and establishing plume stability. Additional sampling points should be considered for the next monitoring event.

Parsons ES Response: *Parsons ES concurs that the number of sampling locations monitored in September 1998 (six) is only marginally adequate for determining plume concentrations, background conditions, and establishing plume stability for a plume of this size. Section 3 will be amended to include a recommendation for considering additional sampling points for future long-term monitoring events.*

## Responses to AFCEE Comments (continued)

Comment 3b) Bioplume II model predictions of plume movement and stability appear to match the observed plume conditions. Natural attenuation still appears to be a viable remedial technique for this site. Field data collected during the next two years will confirm model predictions of plume stability.

Parsons ES Response: *Section 3 will be amended to include a recommendation to continue groundwater monitoring at the site to confirm the stability of the BTEX plume and model predictions.*

**FINAL  
INTRINSIC REMEDIATION  
ENGINEERING EVALUATION/COST ANALYSIS ADDENDUM**

**for**

**UST SITE 870  
HILL AIR FORCE BASE  
OGDEN, UTAH**

**September 1999**

**Prepared for:**

**AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE  
BROOKS AIR FORCE BASE  
SAN ANTONIO, TEXAS**

**AND**

**HILL AIR FORCE BASE  
OGDEN, UTAH**

**Prepared by:**

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## LIST OF ACRONYMS AND ABBREVIATIONS

|                   |   |
|-------------------|---|
| AFCEE             | Air Force Center for Environmental Excellence |
| Parsons ES        | Parsons Engineering Science, Inc.             |
| EE/CA             | Engineering Evaluation/Cost Analysis          |
| UST               | underground storage tank                      |
| AFB               | Air Force Base                                |
| LTM               | long-term monitoring                          |
| USEPA             | US Environmental Protection Agency            |
| NRMRL             | National Risk Management Research Laboratory  |
| BTEX              | benzene, toluene, ethylbenzene, and xylenes   |
| DO                | dissolved oxygen                              |
| redox             | oxidation-reduction                           |
| ORP               | oxidation-reduction potential                 |
| TMBs              | trimethylbenzenes                             |
| MTBE              | methyl tert-butyl ether                       |
| ft/ft             | foot/foot                                     |
| µg/L              | micrograms per liter                          |
| mV                | millivolts                                    |
| mg/L              | milligrams per liter                          |
| CaCO <sub>3</sub> | calcium carbonate                             |

## 1.0 INTRODUCTION

This report was prepared for the Air Force Center for Environmental Excellence (AFCEE) by Parsons Engineering Science, Inc. (Parsons ES) as an update to the *Final Intrinsic Remediation Engineering Evaluation/Cost Analysis (EE/CA) for Underground Storage Tank (UST) Site 870, Hill Air Force Base (AFB), Utah* (Parsons ES, 1995). The EE/CA was conducted to evaluate the use of intrinsic remediation with long-term monitoring (LTM) for remediation of fuel hydrocarbon contamination dissolved in groundwater at UST Site 870. This update summarizes the results of the third sampling event performed as part of long-term groundwater monitoring at the site. This sampling was conducted in September 1998 by researchers from the US Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL) Subsurface Protection and Remediation Division. The original EE/CA sampling event was conducted in August 1993 with the first long-term sampling occurring in July 1994 and the second long-term sampling occurring in September 1995. The main emphasis of this summary is to evaluate changes in dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations, plume extent, and natural attenuation mechanisms through time. Results, calculations, and predictions presented in the EE/CA are used as the basis for comparison.

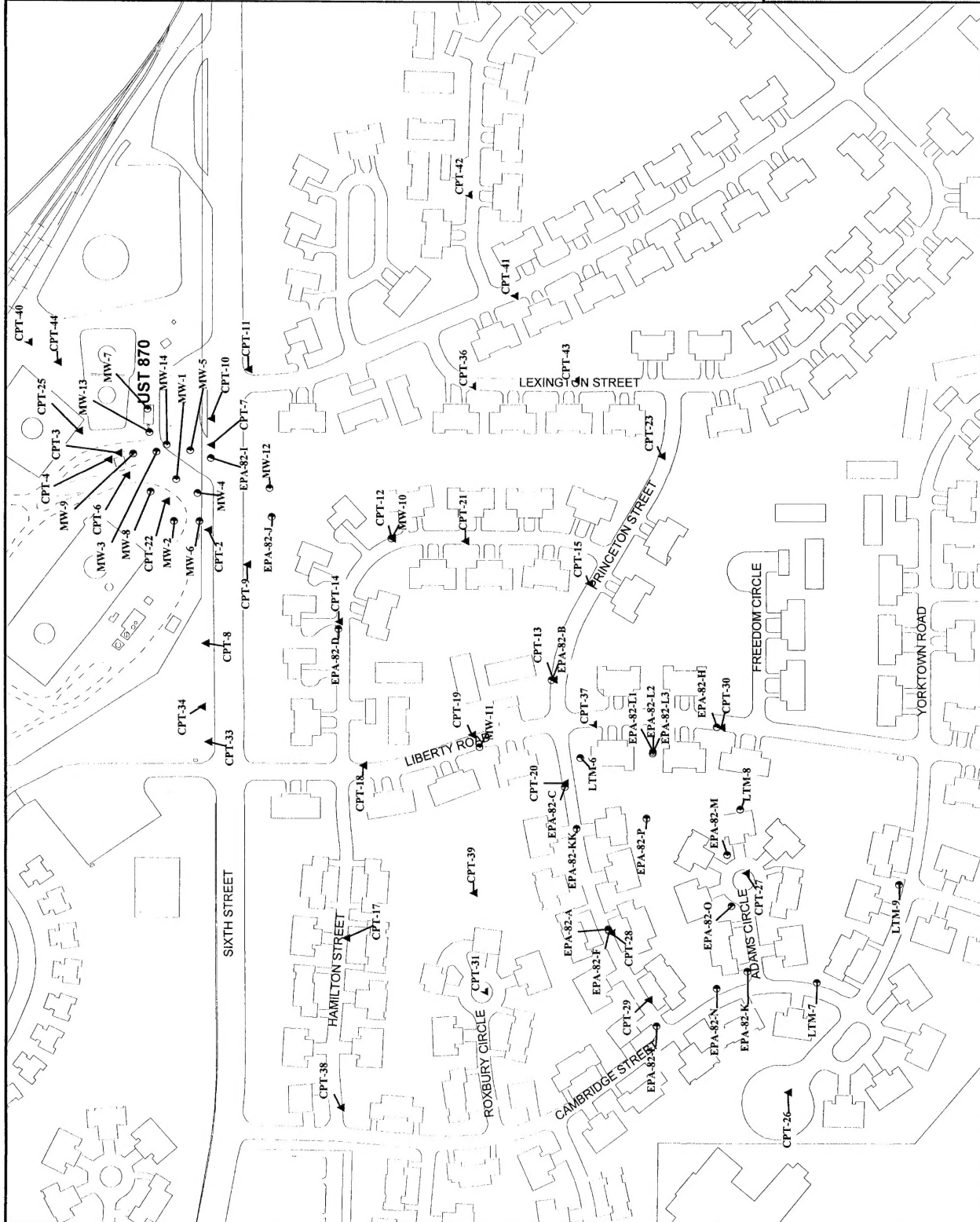
UST Site 870 is located in the southwestern corner of Hill AFB, Utah and encompasses the area immediately downgradient from and adjacent to the former location of UST 870 (Figure 1). The Base fuel tank farm and a portion of the Patriot Hills Base housing area located southwest of the tank farm are also included with the site. Hill Field elementary school is located immediately southwest of the housing area near the southwestern property boundary of the Base. Potential sources of contamination at UST Site 870 include: UST 870, leaky piping associated with the UST, surface spills and releases from tank farm operations since the 1940s, and a faulty 6-inch-diameter pipe located behind the pump facility Building 870 (pending repairs). Additional site information, including site background, geology, and hydrogeology, is provided in the EE/CA (Parsons ES, 1995).

In 1993 and 1995, bail-down tests and pilot scale bioslurping occurred at a monitoring well located near the source area (Leeson *et al.*, 1996). However, being pilot scale and lasting only a few days, these activities did not remove a significant volume of free product. Additionally, on-going free product recovery using sorbent pads has occurred on a monthly basis in seven of the most contaminated site wells since 1996 (Greeley, 1999). Free product recovery via the sorbent pad technique has resulted in the removal of approximately 3 to 5 gallons per month, totaling approximately 110 to 180 gallons of free product.

## 2.0 MONITORING RESULTS

On September 1, 1998, researchers from the USEPA NRMRL collected groundwater samples from 6 monitoring wells at UST Site 870 (EPA-82-D, EPA-82-I, and LTM-6 through 9). Samples were analyzed in the field for dissolved oxygen (DO), temperature, pH, conductivity, oxidation-reduction (redox) potential (ORP), alkalinity, and ferrous iron. Additional sample volume was analyzed at the USEPA NRMRL in Ada, Oklahoma for BTEX, trimethylbenzenes (TMBs), methyl tert-butyl ether (MTBE), and sulfate. Analytical





# LEGEND

- MW-10 Groundwater Monitoring Point
- CPT-39 Cone Penetrometer
- Test Point/Piezometer

0 100 200 Feet



FIGURE 1

## GROUNDWATER MONITORING WELLS AND CPT LOCATIONS

UST Site 870  
Intrinsic Remediation EE/CA Addendum  
Hill Air Force Base, Utah

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methods used are summarized in Table 1. Prior to purging and sampling each well, groundwater levels were measured to the nearest 0.1 foot. Groundwater elevations are presented in Table 2. Analytical results are presented in Appendix A and are summarized in Tables 3 and 4.

## **2.1 Flow Direction and Gradient**

Depth to groundwater was measured in each of the sampled wells in September 1998 (Table 2). However, because no datum elevation was noted for four of the wells, it was only possible to determine groundwater elevations in two of the six wells sampled. Based on the limited groundwater elevation data available for the September 1998 sampling event, groundwater elevation contour maps for this most recent sampling event were not prepared. However, groundwater elevation contour maps for August 1993 and September 1995 are presented on Figure 2. Groundwater in the vicinity of UST Site 870 has historically flowed to the southwest at a gradient of approximately 0.048 foot per foot (ft/ft).

## **2.2 Dissolved BTEX Contamination**

BTEX compounds were detected in groundwater samples from all six of the monitoring wells included in the September 1998 sampling round. BTEX concentrations measured in groundwater samples collected during the September 1998 sampling event are presented in Table 3. In order to evaluate trends in BTEX concentrations and distribution through time, the areal distributions of total dissolved BTEX for August 1993, July 1994, September 1995, and September 1998 are presented on Figure 3. Data that were believed to be unrepresentative of the contaminated zone (e.g., well screen not appropriately located) were not used for contouring. These values are identified on Figure 3 with an asterisk. Results of the September 1998 sampling event indicate that the total BTEX plume is approximately 1,950 feet long (Figure 3). The plume appears to extend approximately 450 feet further downgradient than in 1993, approximately 350 feet further downgradient than in 1994, and is approximately equal to the downgradient position of the plume in 1995. The areal extent of the plume does not appear to have changed significantly since 1995, suggesting that the plume has reached steady state. It should be noted that the downgradient extent of the BTEX plume in 1993 and 1994 were not known with precision. Therefore, the inferred plume expansion described above is speculative.

Given an advective groundwater velocity of approximately 1,600 feet per year and an estimated retardation coefficient for benzene of 1.29 (Parsons ES, 1995), the plume potentially could have migrated approximately 6,200 feet in the five years from August 1993 to September 1998 if biodegradation were not occurring. The estimated difference in plume length from 1993 to 1998 is only approximately 450 feet. Reduced plume migration rates provide strong evidence supporting the occurrence of bioremediation.

The inferred rate of plume expansion is similar to the rate predicted by the Bioplume II models presented in the EE/CA (Parsons ES, 1995). All three variations of the model predicted similar rates of plume expansion along the leading edge of the plume during the first few simulation years. In particular, these model simulations predicted that the plume would reach the intersection of Cambridge Street and Adams Circle approximately one year after August 1993. In actuality, the plume appears to have migrated beyond this intersection at some point during the second year, and by the end of the second year extended

**TABLE 1**  
**SUMMARY OF GROUNDWATER ANALYTICAL METHODS**  
**UST SITE 870**  
**INTRINSIC REMEDIATION EE/CA ADDENDUM**  
**HILL AIR FORCE BASE, UTAH**

| Analyte                           | Method                           | Field (F) or<br>Fixed-Base<br>Laboratory (L) |
|-----------------------------------|----------------------------------|--|
| Reduction/Oxidation Potential     | Direct reading meter             | F  |
| Dissolved Oxygen                  | Direct reading meter             | F  |
| pH                                | Direct reading meter             | F  |
| Conductivity                      | Direct reading meter             | F  |
| Temperature                       | Direct reading meter             | F  |
| Ferrous Iron ( $\text{Fe}^{2+}$ ) | Colorimetric, HACH Method 8146   | F  |
| Hydrogen Sulfide                  | HACH HS-C                        | F  |
| Carbon Dioxide                    | Titrimetric, HACH Method 1436-01 | F  |
| Alkalinity (as $\text{CaCO}_3$ )  | Titrimetric, HACH Method 8221    | F  |
| Methane, Ethane, and Ethene       | RSKSOP-194, -175 <sup>a/</sup>   | L  |
| Sulfate                           | Waters Capillary Electrophoresis | L  |
| Total Organic Carbon              | RSKSOP-102                       | L  |
| BTEX, TMB, MTBE, and fuel carbon  | RSKSOP-133                       | L  |

<sup>a/</sup> RSKSOP = Robert S. Kerr Laboratory (now known as NRMRL) standard operating procedure.

**TABLE 2**  
**GROUNDWATER ELEVATION DATA**  
**UST SITE 870**  
**INTRINSIC REMEDIATION EE/CA ADDENDUM**  
**HILL AIR FORCE BASE, UTAH**

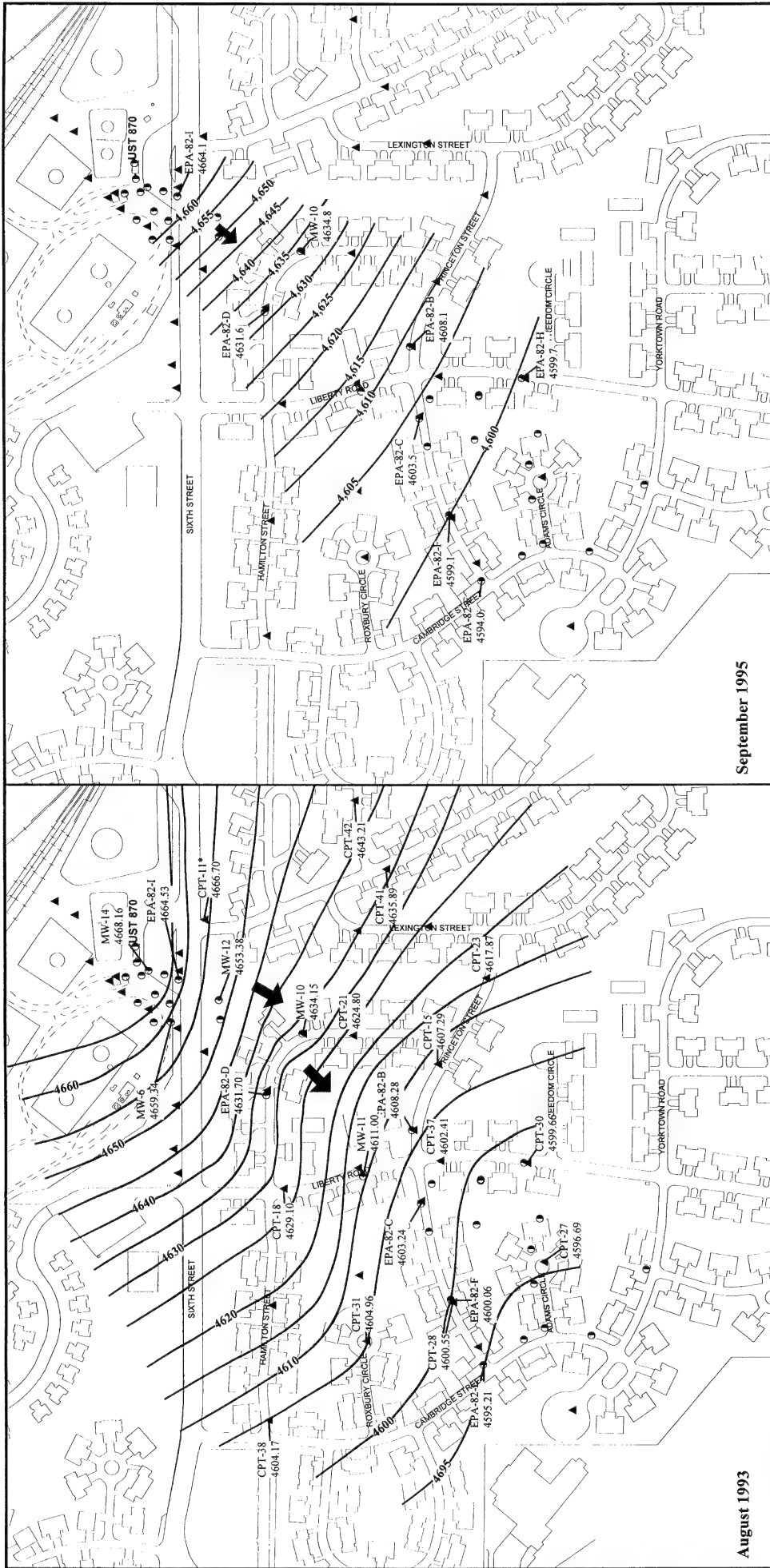
| Sample<br>Location | Datum<br>Elevation<br>(ft msl) <sup>a/</sup> | Sample<br>Date | Measured Depth<br>to Water<br>(ft BTOC) <sup>b/</sup> | Groundwater<br>Elevation<br>(ft msl) |
|--------------------|--|----------------|---|--------------------------------------|
| EPA-82-D           | 4655.39                                      | 9/1/1998       | 22.56   | 4632.83                              |
| EPA-82-I           | 4683.08                                      | 9/1/1998       | 16.90   | 4666.18                              |
| LTM-6              | NM <sup>c/</sup>                             | 9/1/1998       | 23.60   | NA <sup>d/</sup>                     |
| LTM-7              | NM   | 9/1/1998       | 8.58  | NA                                   |
| LTM-8              | NM   | 9/1/1998       | 10.02   | NA                                   |
| LTM-9              | NM   | 9/1/1998       | 11.28   | NA                                   |

<sup>a/</sup>ft msl = Feet above Mean Sea Level.

<sup>b/</sup>ft BTOC = Feet Below Top of Casing.

<sup>c/</sup>NM = Not Measured.

<sup>d/</sup>NA = Not Applicable.



August 1993

September 1995

# LEGEND

- EPA-82-E Groundwater Monitoring Well With
- 4595.21 Groundwater Elevation (feet above mean sea level)
- CPT-11 Cone Penetrometer Test Point/Piezometer With
- 4666.70 Groundwater Elevation (feet above mean sea level)
- Groundwater Surface Elevation Contour
- Inferred Direction of Groundwater Flow

\* = These data were not used in the generation of contour lines.

FIGURE 2

## GROUNDWATER ELEVATION CONTOUR MAPS AUGUST 1993 AND SEPTEMBER 1995

UST Site 870  
Intrinsic Remediation EE/CA Addendum  
Hill Air Force Base, Utah

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**TABLE 3**  
**FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUNDWATER**  
**UST SITE 870**  
**INTRINSIC REMEDIATION EE/CA ADDENDUM**  
**HILL AIR FORCE BASE, UTAH**

| Sample Location | Sample Date | Benzene (µg/L) <sup>d/</sup> | Toluene (µg/L) | Ethylbenzene (µg/L) | P-Xylene (µg/L) | M-Xylene (µg/L) | O-Xylene (µg/L) | Total Xylenes (µg/L) | Total BTEX <sup>a/</sup> (µg/L) | 1,3,5-TMB <sup>b/</sup> (µg/L) | 1,2,4-TMB (µg/L) | 1,2,3-TMB (µg/L) | MTBE <sup>c/</sup> (µg/L) |
|-----------------|-------------|------------------------------|----------------|---------------------|-----------------|-----------------|-----------------|----------------------|---------------------------------|--------------------------------|------------------|------------------|---------------------------|
| EPA-82-D        | Sep-98      | 3.4                          | 2.5            | 47.4                | 55.9            | 94.5            | 30.2            | 180.6                | 233.9                           | 97.2                           | 182.3            | 77.3             | 4.0                       |
| EPA-82-I        | Sep-98      | 2959                         | 2363           | 608.6               | 1161            | 3473            | 1648            | 6282                 | 12212.6                         | 334.2                          | 767.1            | 265.1            | 3.4                       |
| LTM-6           | Sep-98      | 19.3                         | 11.4           | 346                 | 655.6           | 1714            | 657.7           | 3027.3               | 3404                            | 341                            | 753.6            | 300.1            | 1.8                       |
| LTM-7           | Sep-98      | ND <sup>e/</sup>             | ND             | <1 <sup>f/</sup>    | 1.2             | 2.2             | <1              | 3.4                  | 3.4                             | ND                             | 1.5              | <1               | <1                        |
| LTM-8           | Sep-98      | 7.9                          | 7.5            | 283                 | 589.3           | 1516            | 738.2           | 2843.5               | 3141.9                          | 337.3                          | 766.2            | 308.6            | 3.4                       |
| LTM-9           | Sep-98      | ND                           | ND             | 1.5                 | 13.8            | 5.3             | 8.7             | 27.8                 | 29.3                            | 4.3                            | 14.9             | 13.3             | <1                        |

<sup>a/</sup> BTEX = Benzene, toluene, ethylbenzene, and xylenes.

<sup>b/</sup> TMB = Trimethylbenzene.

<sup>c/</sup> MTBE = Methyl tert-butyl ether.

<sup>d/</sup> µg/L = Micrograms per liter.

<sup>e/</sup> ND = Analyte not detected in this sample.

<sup>f/</sup> <1 = Below identified limit of quantification.

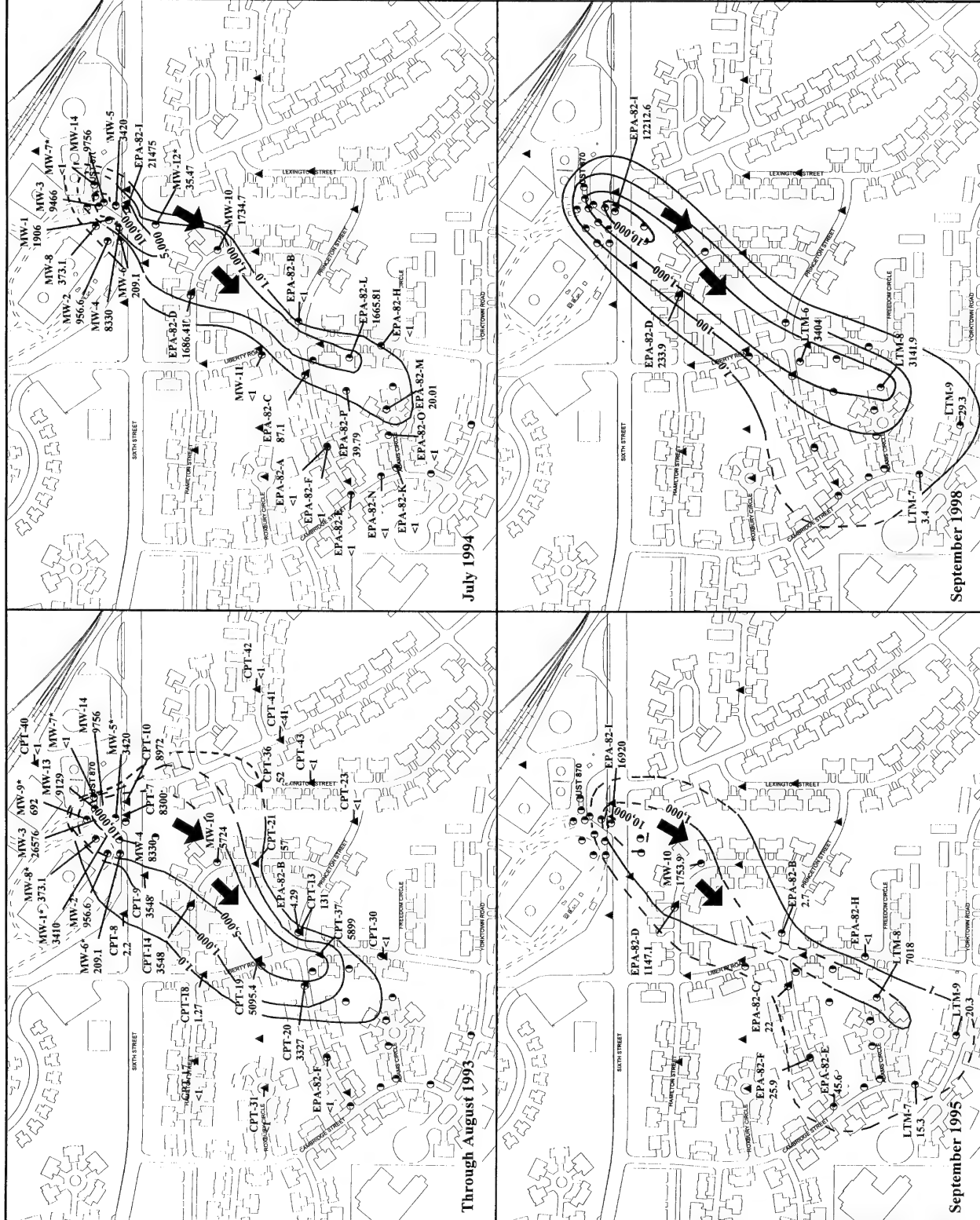


FIGURE 3

# TOTAL BTEX IN GROUNDWATER

UST Site 870  
Intrinsic Remediation EE/CA Addendum  
Hill Air Force Base, Utah

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approximately 200 feet downgradient from this intersection. Furthermore, the Bioplume II model predicted that the plume would reach steady-state equilibrium within four years after August 1993, and would start to recede by the year 2003. Consistent with the model predictions, the plume appears to have reached steady-state equilibrium by September 1995 (year 2 of simulation), and maintained its downgradient position between September 1995 and September 1998 (year 5 of simulation).

By September 1995, not only had the BTEX plume appeared to have migrated downgradient from its July 1994 position, but the width of the downgradient portion of the plume also had expanded. This expansion can be observed in Figure 3 as a lobe extending to the west along Cambridge Street. Total BTEX concentrations in the lobe did not exceed 50 micrograms per liter ( $\mu\text{g/L}$ ) in September 1995. Historically however, concentrations of dissolved BTEX were not detected in this area of the site. The continued presence of this lobe in September 1998 was not verified.

Total BTEX concentrations measured in samples collected from monitoring well EPA-82-I, located near the original source area, have decreased from 21,475  $\mu\text{g/L}$  in July 1994, to 16,920  $\mu\text{g/L}$  in September 1995, to 12,213  $\mu\text{g/L}$  in September 1998 (Figure 3). Reductions in source area concentrations can be attributed primarily to the operation of natural attenuation processes given the continued presence of free product in the source area. Changes in total BTEX concentrations at monitoring wells that were sampled in both September 1995 and September 1998 are presented on Figure 4. Total BTEX concentrations decreased over time in four of the five wells that were sampled during both events. Observed decreases in total BTEX concentrations in these four wells indicate that the overall magnitude of dissolved BTEX concentrations is decreasing. This decrease should eventually cause the plume to recede toward the source area.

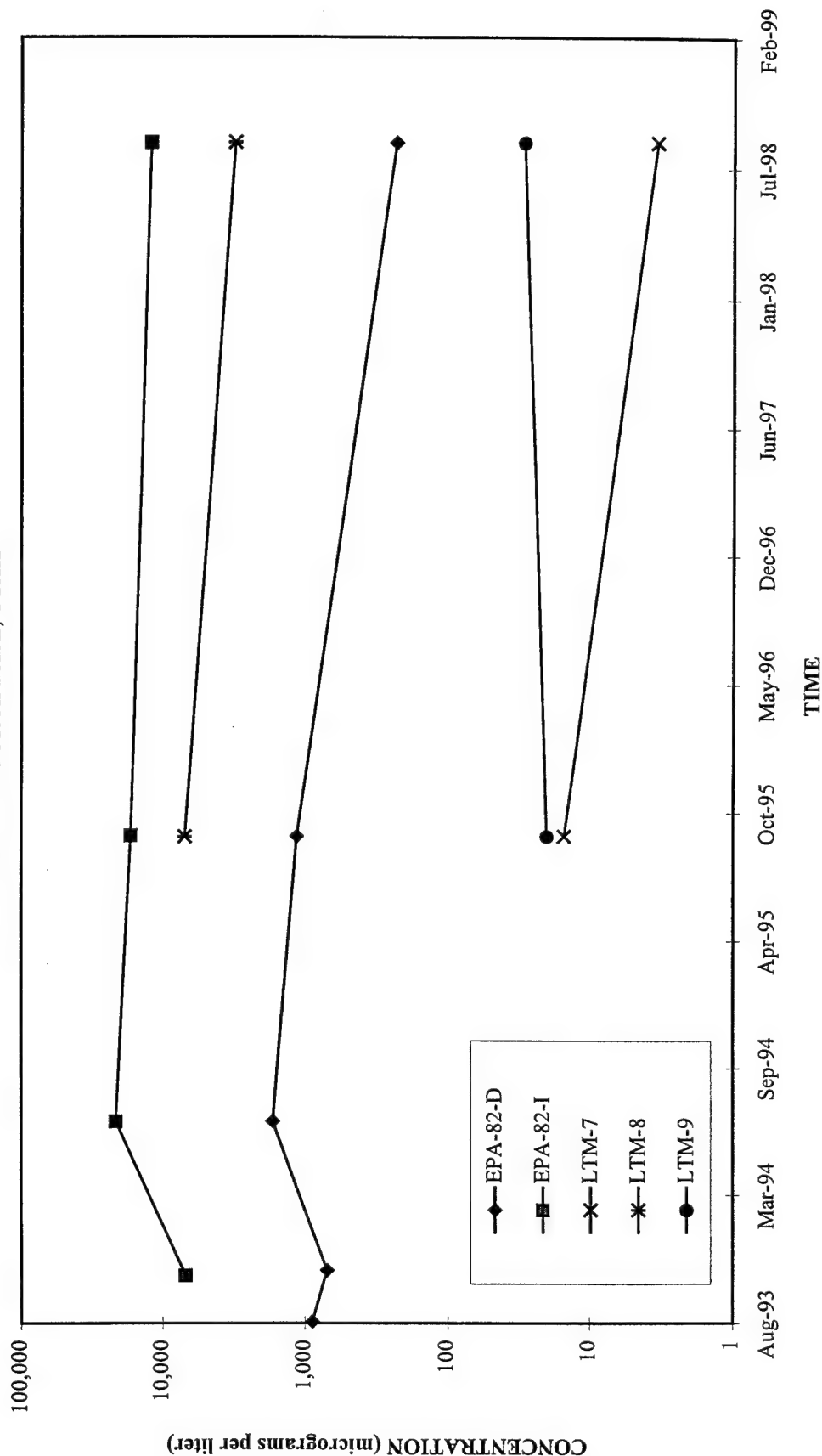
### 2.3 Inorganic Chemistry and Geochemical Indicators of Biodegradation

As discussed in the EE/CA, microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous oxidation/reduction reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at UST Site 870 are natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states and include oxygen, nitrate, ferrous iron, sulfate, and carbon dioxide. Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). Dissolved oxygen is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms use electron acceptors in the following order of preference: nitrate, ferric iron, sulfate, and finally carbon dioxide. Anaerobic destruction of the BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990).

ORP, a measure of the relative tendency of a solution to accept or transfer electrons, was measured at the six wells sampled during September 1998. The dominant electron acceptor



**FIGURE 4**  
**TOTAL BTX IN GROUNDWATER OVER TIME**  
 UST SITE 870  
 INTRINSIC REMEDIATION EE/CA ADDENDUM  
 HILL AIR FORCE BASE, UTAH



being reduced by microbes during BTEX oxidation is related to the ORP of the groundwater. ORP measured at the site in September 1998 is summarized in Table 4. Concentration contour maps of ORP measured at the site in August 1993, July 1994, September 1995, and September 1998 are presented on Figure 5. Data that were believed to be unrepresentative of the contaminated zone (e.g., well screen not appropriately located) were not used for contouring. These values are identified on Figure 5 with an asterisk. The ORPs measured in September 1998 at UST Site 870 range from -199 millivolts (mV) to 150 mV. Comparison of Figures 3 and 5 shows that areas of the site with low ORP coincide with areas characterized by high dissolved BTEX concentrations.

The change in ORP over time at wells sampled in 1998 is shown on Figure 6. The most significant difference in ORPs between the August 1993 and September 1995 sampling events is a continuous decrease in the lowest measured site ORPs. The lowest observed site ORP decreased from -125 mV in August 1993, to -190 mV in July 1994, to -300 mV in September 1995. This trend indicates that sulfate reduction and methanogenesis were increasingly important biodegradation processes during that period. However, results of the September 1998 sampling event indicate a more oxidizing groundwater environment across the site. Additional ORP data are required to assess whether this is a continuing trend or indicative of natural temporal variability.

DO concentrations were measured at all six groundwater sampling locations monitored in September 1998 (Table 4). Contour maps of DO concentrations measured at the site in 1993, 1994, 1995, and 1998 are shown on Figure 7. Data that were believed to be unrepresentative of the contaminated zone (e.g., well screen not appropriately located) were not used for contouring. These values are identified on Figure 7 with an asterisk. Comparison of Figures 3 and 7 shows that areas with elevated total BTEX concentrations have depleted DO concentrations, with the lowest DO concentrations occurring through the core of the dissolved BTEX plume. The correlation between depleted DO and elevated BTEX concentrations is a strong indication that aerobic biodegradation of the BTEX compounds has occurred at the site.

Changes in DO over time at selected wells are shown on Figure 8. DO concentrations at wells EPA-82-D and LTM-8 have remained less than 0.5 milligrams per liter (mg/L), indicating the continued presence of anaerobic conditions at these locations. Aerobic conditions were encountered at LTM-7, located downgradient from the dissolved BTEX plume, during both 1995 and 1998. The dramatic increase in DO concentrations at EPA-82-I is anomalous given the continued presence of elevated dissolved BTEX concentrations at this location. The greatest aerobic activity is expected to occur at the upgradient perimeter of the source area and along the fringes of the plume, because these are areas where BTEX-contaminated groundwater interacts with groundwater containing the highest concentrations of DO. DO concentrations in groundwater have decreased at monitoring well LTM-9, perhaps reflecting the migration of oxygen-depleted groundwater from the plume core area.

Nitrate concentrations were not measured during the September 1998 sampling event. However, concentration contour maps of nitrate measured in August 1993, July 1994, and September 1995, presented on Figure 9, show that areas of depleted nitrate concentrations coincide with areas of high BTEX concentrations. This observation, in conjunction with

**TABLE 4**  
**GROUNDWATER GEOCHEMICAL DATA**  
**UST SITE 870**  
**INTRINSIC REMEDIATION EE/CA ADDENDUM**  
**HILL AIR FORCE BASE, UTAH**

| Well ID  | Sample Date | Redox Potential (mV) <sup>c/</sup> | Dissolved Oxygen (mg/L) <sup>d/</sup> | NO <sub>2</sub> +NO <sub>3</sub> (N) <sup>a/</sup> (mg/L) | Ferrous Iron (mg/L) | Sulfate (mg/L) | Methane (mg/L) | Conductivity (μS/cm) <sup>e/</sup> | pH  | Temp. (°C) <sup>f/</sup> | Total Alkalinity (mg/L) | TOC <sup>b/</sup> (mg/L) |
|----------|-------------|------------------------------------|---------------------------------------|---|---------------------|----------------|----------------|------------------------------------|-----|--------------------------|-------------------------|--------------------------|
| EPA-82-D | 9/1/1998    | -199                               | 0.4                                   | NM <sup>g/</sup>  | 2                   | 20             | NM             | 2080                               | 7.4 | 18.5                     | 1360                    | NM                       |
| EPA-82-I | 9/1/1998    | -95.3                              | 7.6                                   | NM  | 8                   | 10             | NM             | 875                                | 7.1 | 17.8                     | 520                     | NM                       |
| LTM-6    | 9/1/1998    | -96.5                              | 10.4                                  | NM  | 10                  | 5.0            | NM             | 1330                               | 7.1 | 18.7                     | 760                     | NM                       |
| LTM-7    | 9/1/1998    | 150                                | 3.5                                   | NM  | <0.1 <sup>b/</sup>  | 10             | NM             | 1640                               | 7.2 | 17.9                     | 600                     | NM                       |
| LTM-8    | 9/1/1998    | -59.5                              | 0.4                                   | NM  | 10                  | 10             | NM             | 1520                               | 7.1 | 14.9                     | 840                     | NM                       |
| LTM-9    | 9/1/1998    | 109                                | 1.2                                   | NM  | <0.1                | 10             | NM             | 1060                               | 7.2 | 16.1                     | 660                     | NM                       |

<sup>a/</sup> NO<sub>2</sub>+NO<sub>3</sub> (N) = Nitrogen as nitrite plus nitrate.

<sup>b/</sup> TOC = Total Organic Carbon.

<sup>c/</sup> mV = Millivolts.

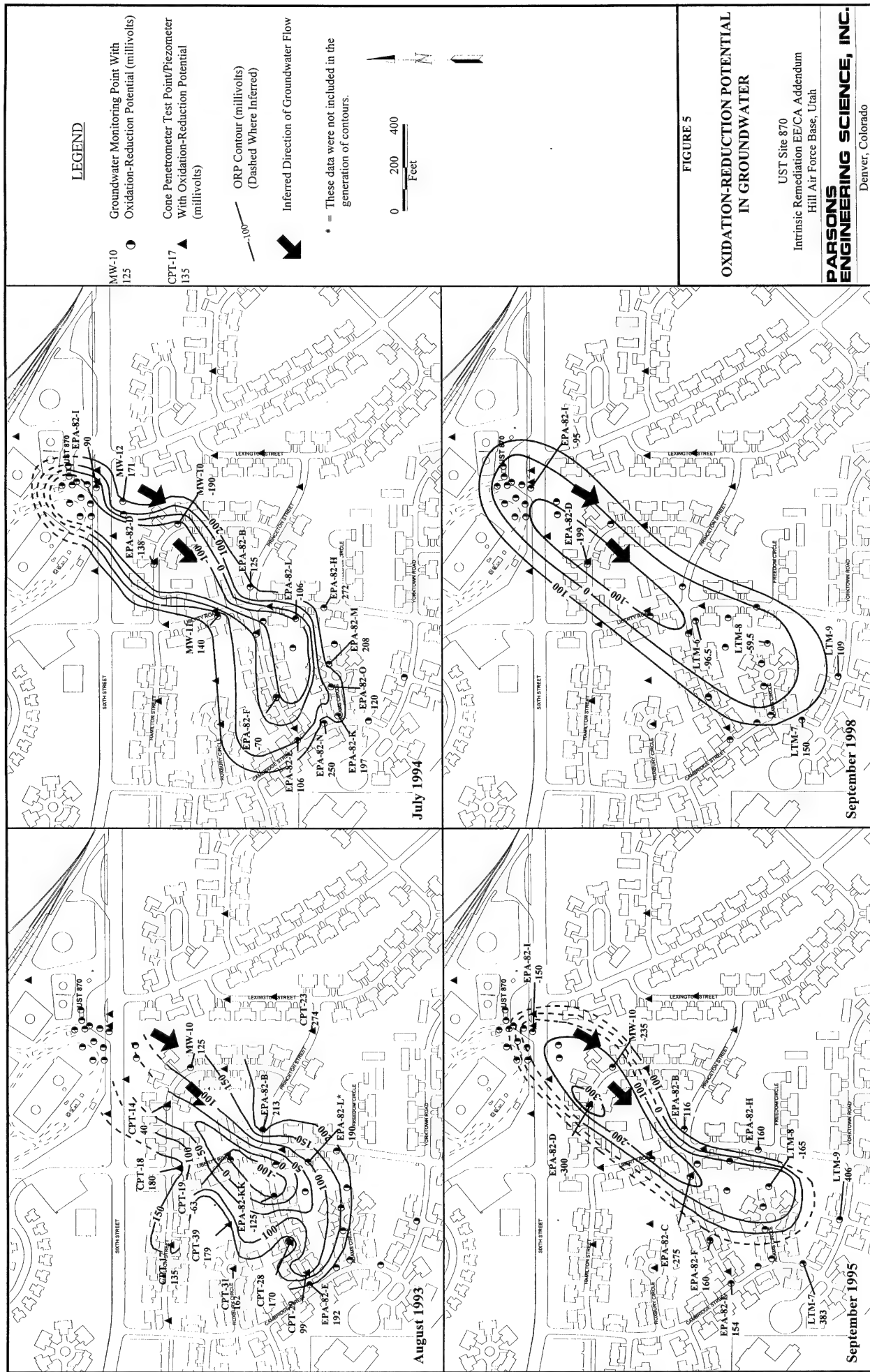
<sup>d/</sup> mg/L = Milligrams per liter.

<sup>e/</sup> μS/cm = Microseimens per centimeter.

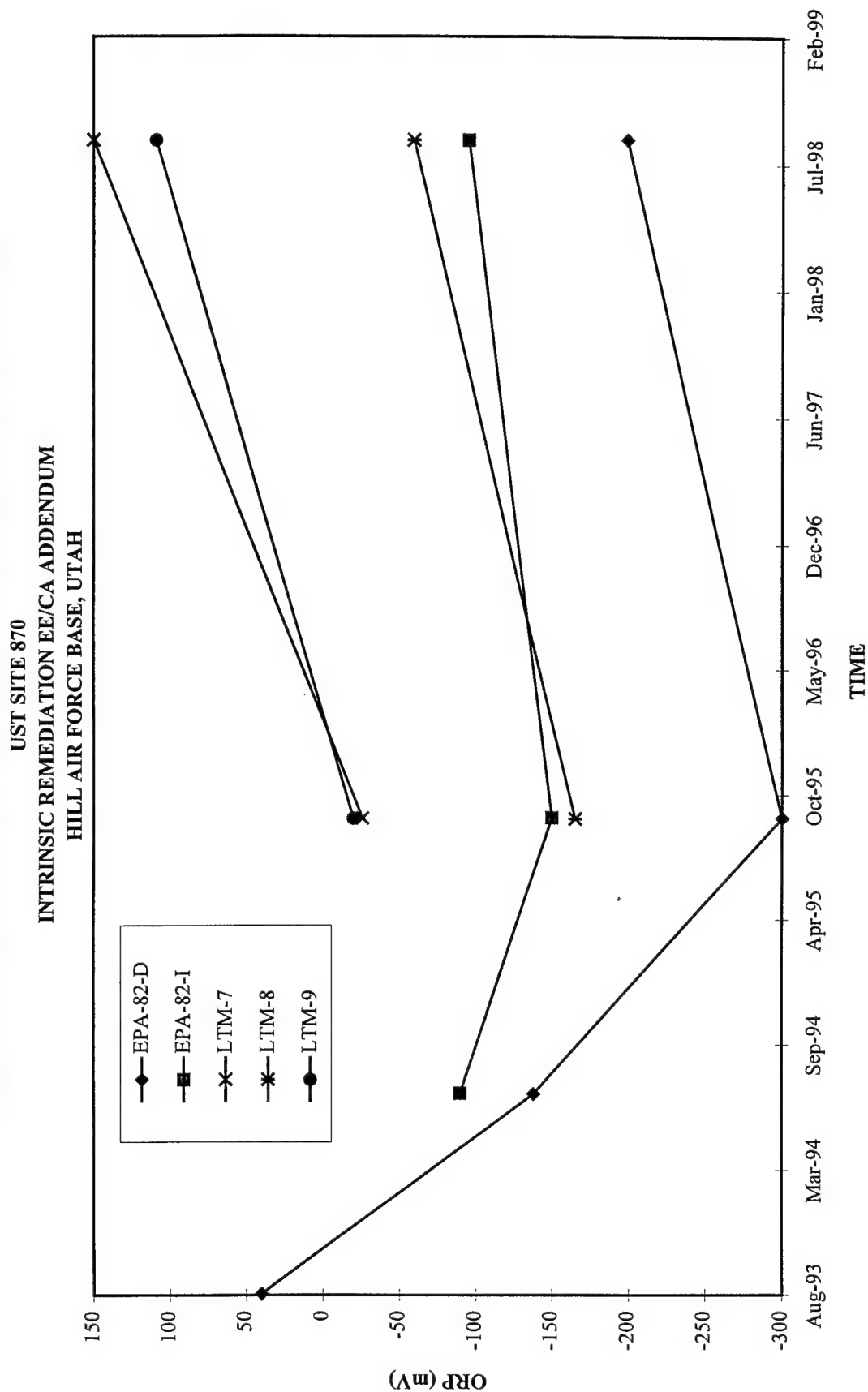
<sup>f/</sup> °C = Degrees Celsius.

<sup>g/</sup> NM = Not Measured.

<sup>h/</sup> <0.1 = Below identified limit of quantification.



**FIGURE 6**  
**OXIDATION-REDUCTION POTENTIAL IN GROUNDWATER OVER TIME**



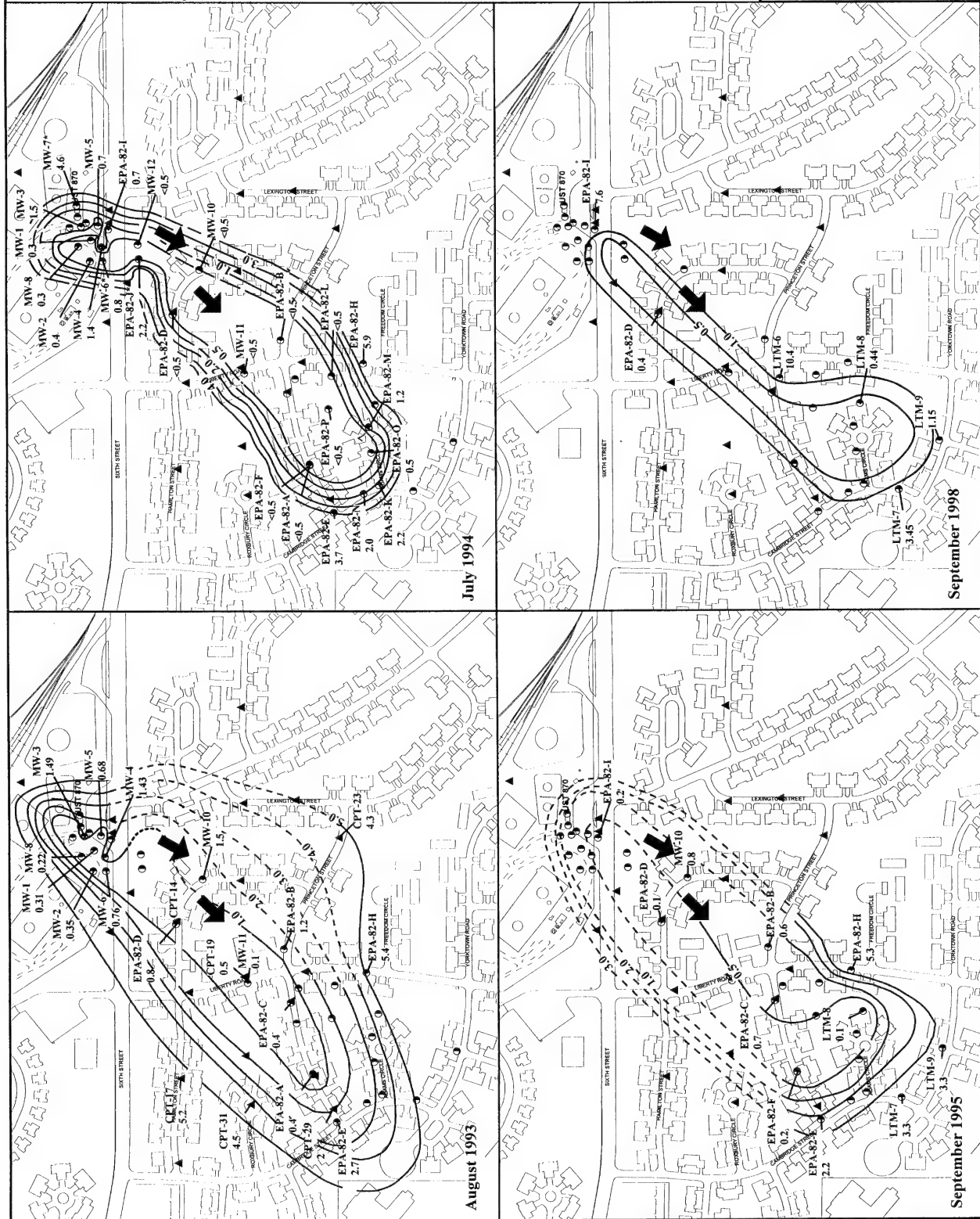


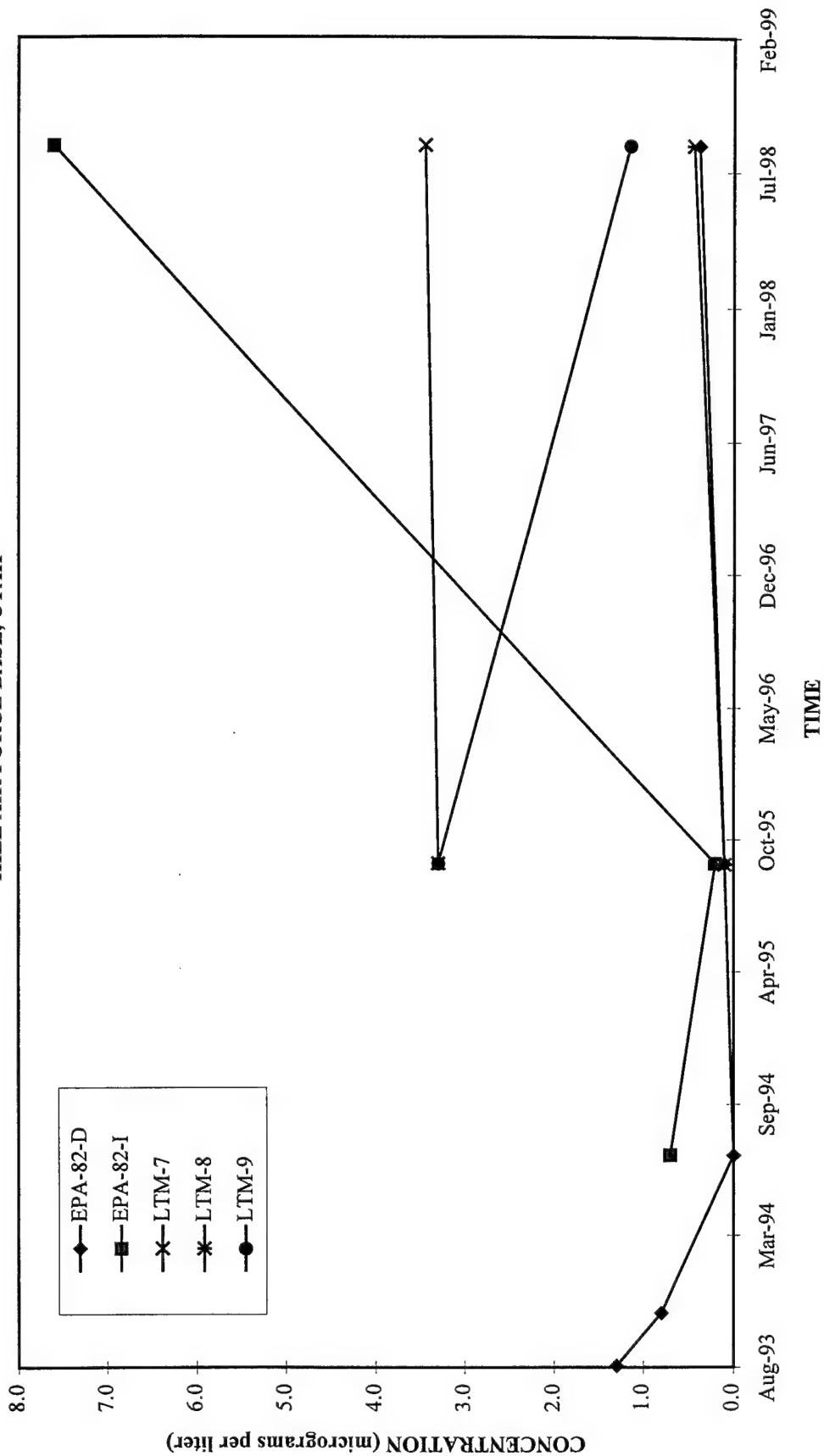
FIGURE 7

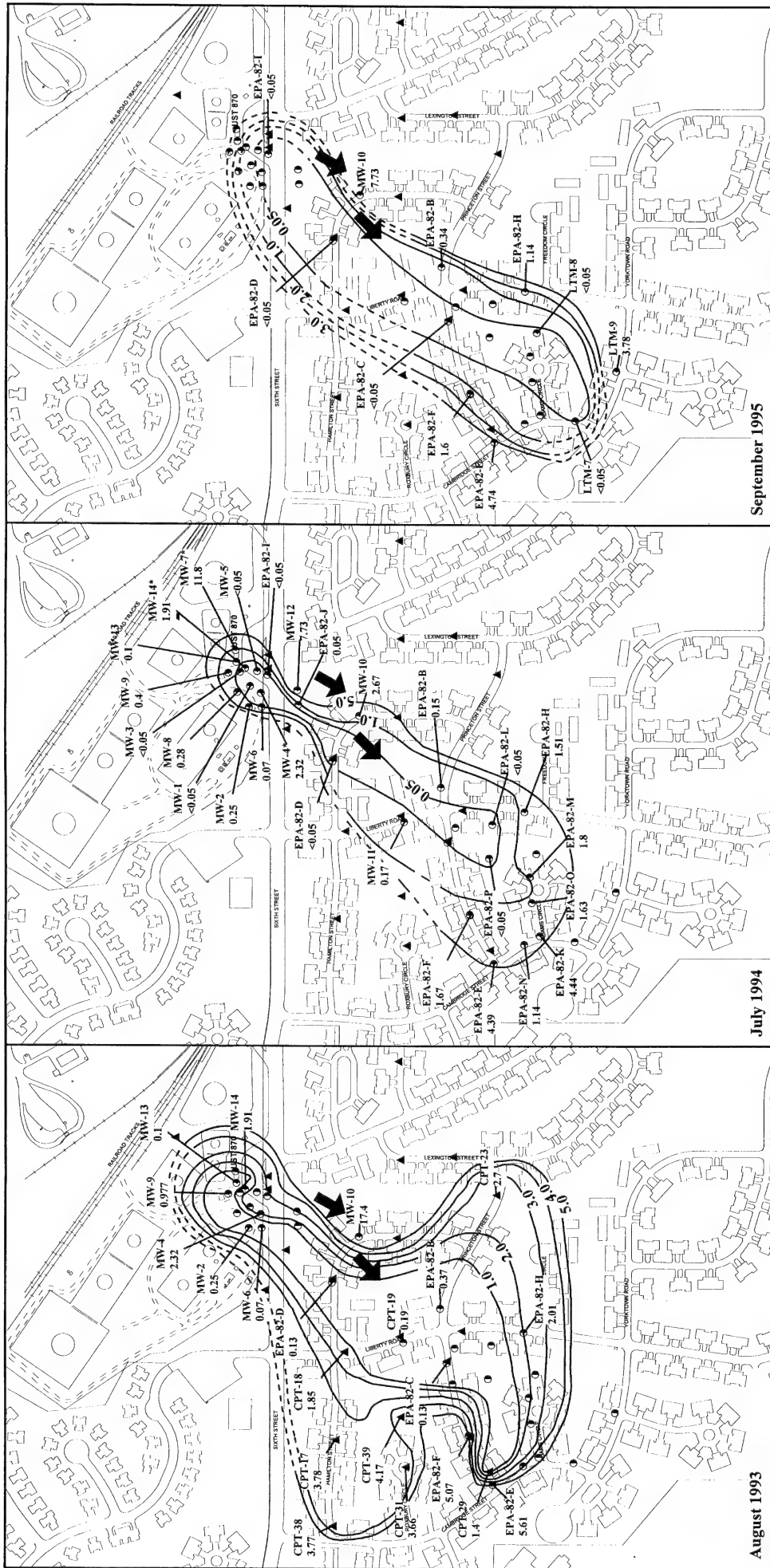
## DISSOLVED OXYGEN IN GROUNDWATER

UST Site 870  
Intrinsic Remediation EE/CA Addendum  
Hill Air Force Base, Utah

**PARSONS  
ENGINEERING SCIENCE, INC.**  
Denver, Colorado

**FIGURE 8**  
**DISSOLVED OXYGEN IN GROUNDWATER OVER TIME**  
 UST SITE 870  
 INTRINSIC REMEDIATION EE/CA ADDENDUM  
 HILL AIR FORCE BASE, UTAH







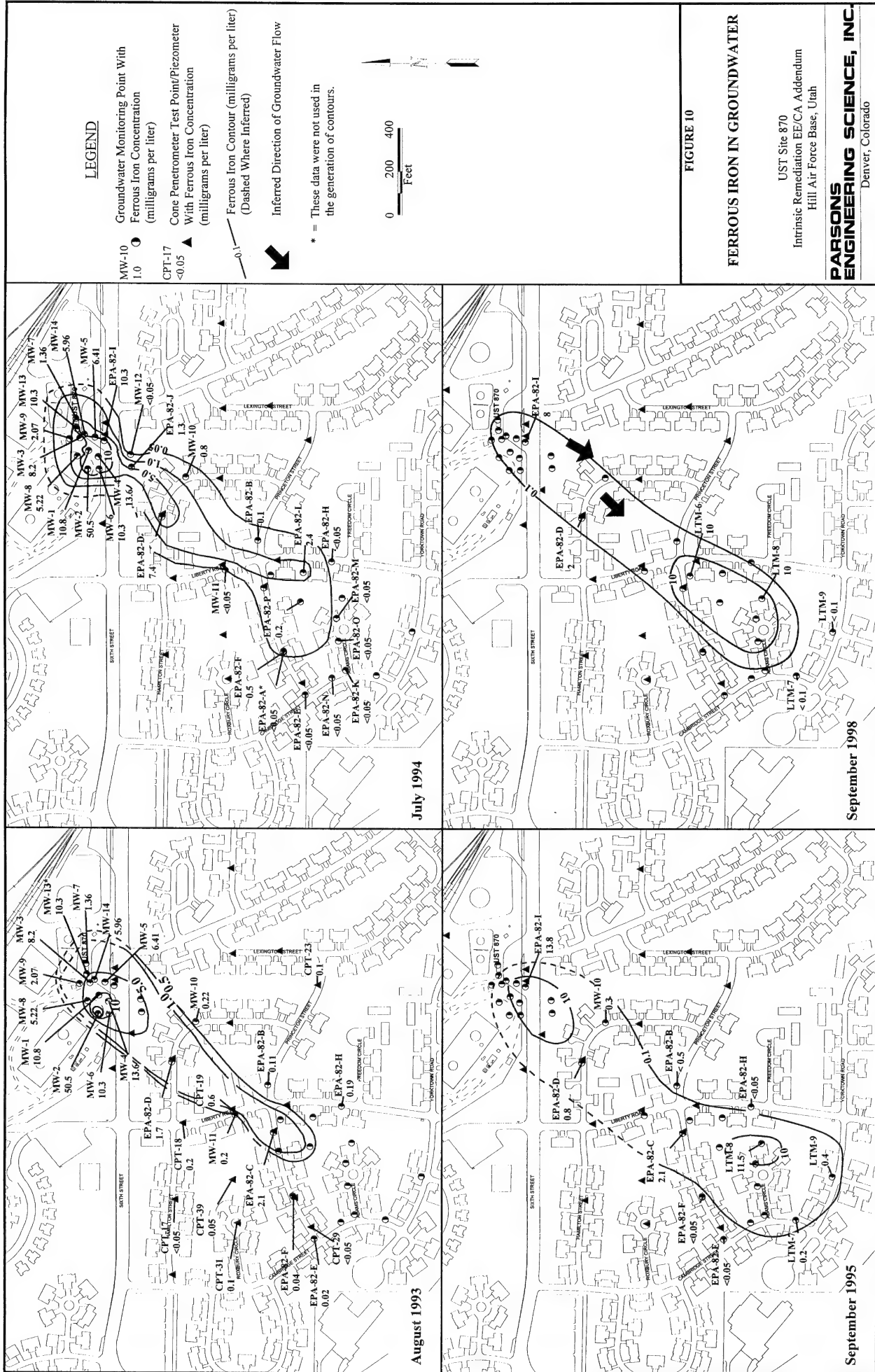
observed ranges of ORP at the site, indicates that fuel hydrocarbon biodegradation via the anaerobic process of denitrification has occurred at the site and is continuing to occur along the plume perimeter.

Ferrous iron is a byproduct of the anaerobic biodegradation process of ferric iron reduction. Accumulation of ferrous iron in groundwater indicates that this microbially assisted process is or has recently occurred. Ferrous iron concentrations were measured at the six sampled locations during the September 1998 sampling event, and are presented in Table 4. Ferrous iron concentration contour maps for 1993, 1994, 1995, and 1998 are shown on Figure 10. Data that were believed to be unrepresentative of the contaminated zone (e.g., well screen not appropriately located) were not used for contouring. These values are identified on Figure 10 with an asterisk. Comparison of Figures 3 and 10 shows that areas with elevated total BTEX concentrations also have increased concentrations of ferrous iron. For example, in September 1998, the two samples with the highest ferrous iron concentration (10 mg/L) were collected from the wells that also contained the highest total dissolved BTEX concentrations downgradient from the source area (LTM-6 and LTM-8). Recent evidence suggests that the reduction of ferric iron to ferrous iron cannot proceed without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993); therefore, presence of ferrous iron strongly suggests that ferric iron is being used as an electron acceptor at the site. Furthermore, the coincident ferrous iron and BTEX plumes indicates that the reduction of ferric iron to ferrous iron is occurring during biodegradation of BTEX compounds.

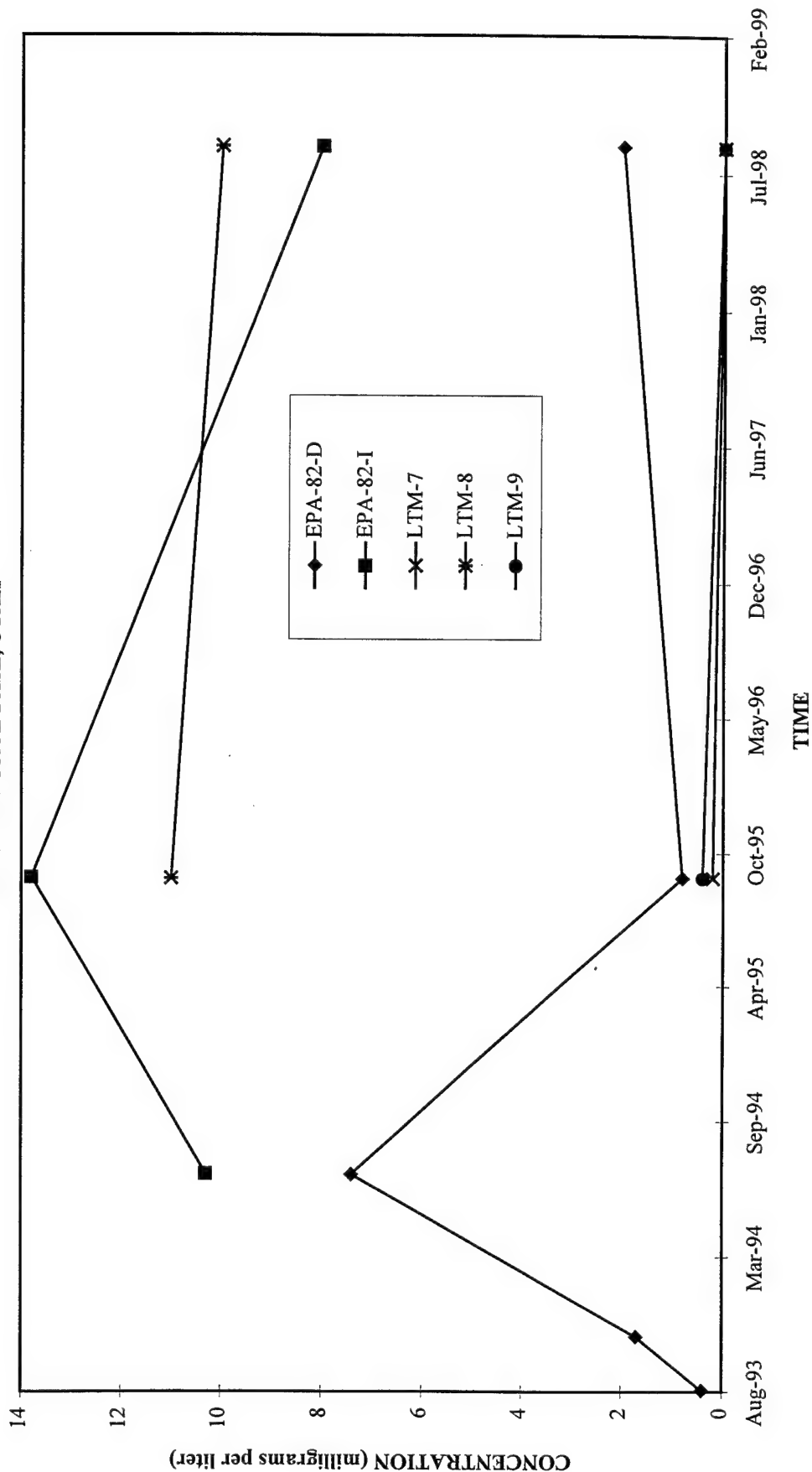
Changes in ferrous iron concentrations over time at selected monitoring wells are shown on Figure 11. The ferrous iron concentrations detected in 1998 are generally similar to those detected in 1995, indicating that fuel hydrocarbon biodegradation via iron reduction continues to occur. The largest change in ferrous iron concentrations occurred at source area well EPA-82-I, where concentrations decreased from 13.8 mg/L in September 1995 to 8 mg/L in September 1998.

Sulfate concentrations were measured at the six locations sampled in September 1998 and are summarized in Table 4. Sulfate concentration contour maps for 1993, 1994, 1995, and 1998 are shown on Figure 12. Data that were believed to be unrepresentative of the contaminated zone (e.g., well screen not appropriately located) were not used for contouring. These values are identified on Figure 12 with an asterisk. Comparison of Figures 3 and 12 shows that the areas with the highest total BTEX concentrations have depleted sulfate concentrations. The correlation of depleted sulfate concentrations with the highest BTEX concentrations provides strong evidence that anaerobic biodegradation of the BTEX compounds is occurring at the site through the microbially mediated process of sulfate reduction. From 1993 to 1994, the data suggest that the areal extent of depleted sulfate concentrations increased at a rapid rate, suggesting that sulfate reduction was becoming an increasingly important process in BTEX biodegradation. Since 1994, the area of depleted sulfate concentrations has remained generally stable, indicating that sulfate reduction is continuing to occur within the BTEX plume.

Changes in sulfate concentrations over time in groundwater at selected monitoring wells are shown on Figure 13. Of the five wells for which comparative historical data exists,



**FIGURE 11**  
**FERROUS IRON IN GROUNDWATER OVER TIME**  
 UST SITE 870  
 INTRINSIC REMEDIATION EE/CA ADDENDUM  
 HILL AIR FORCE BASE, UTAH



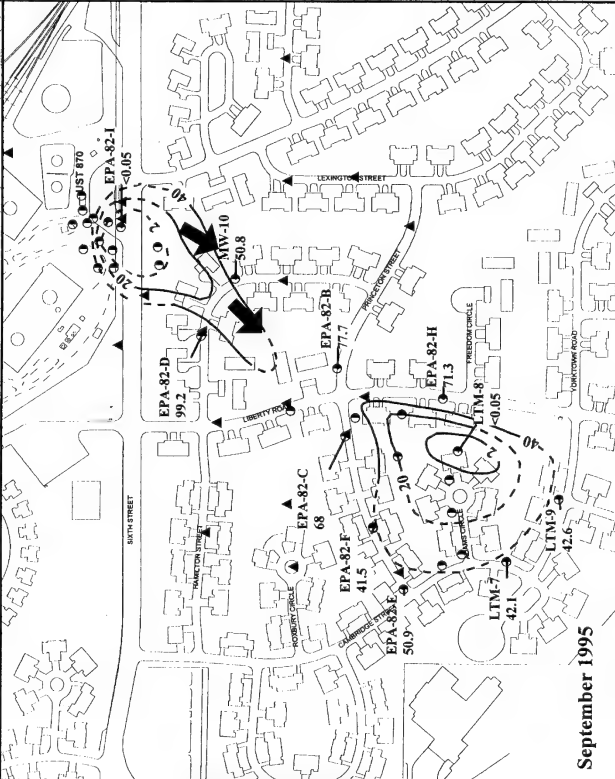
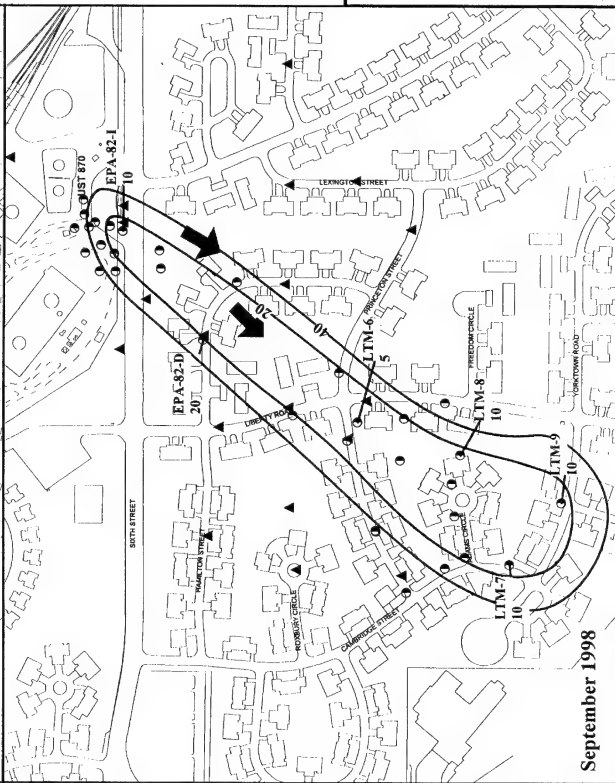
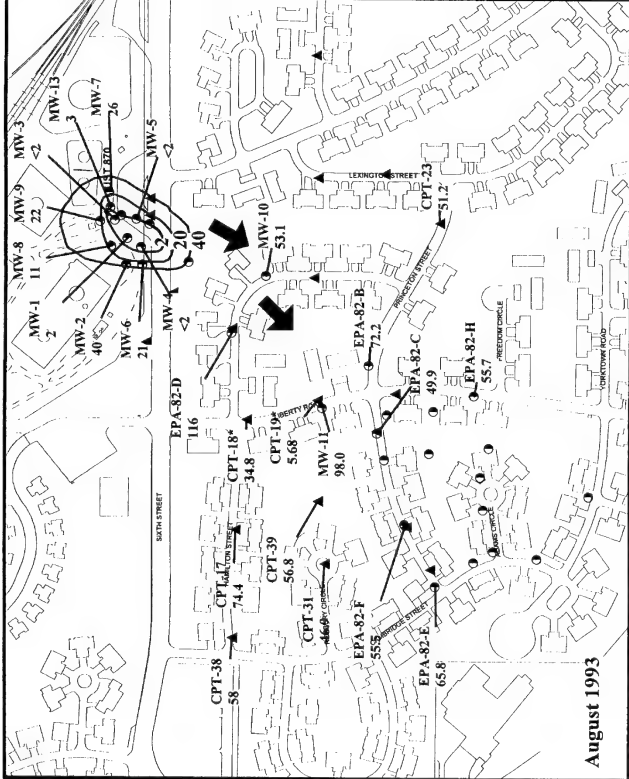
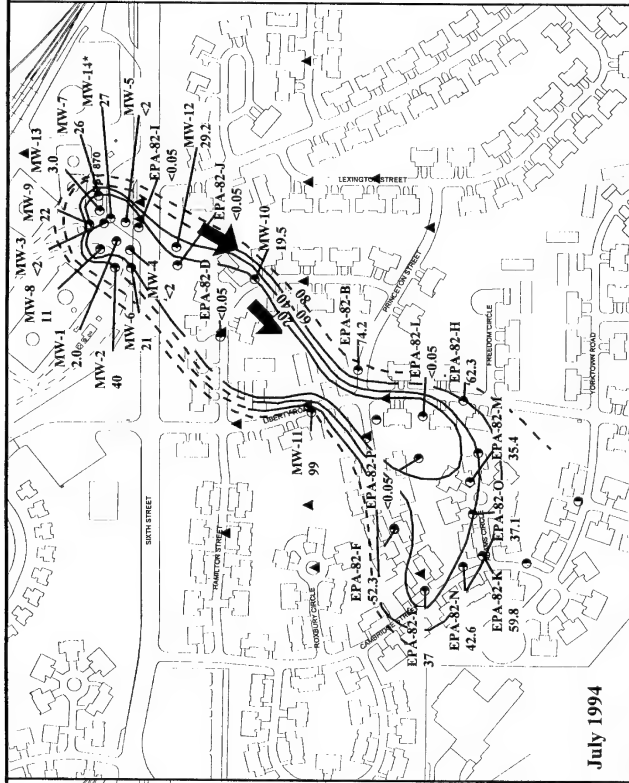


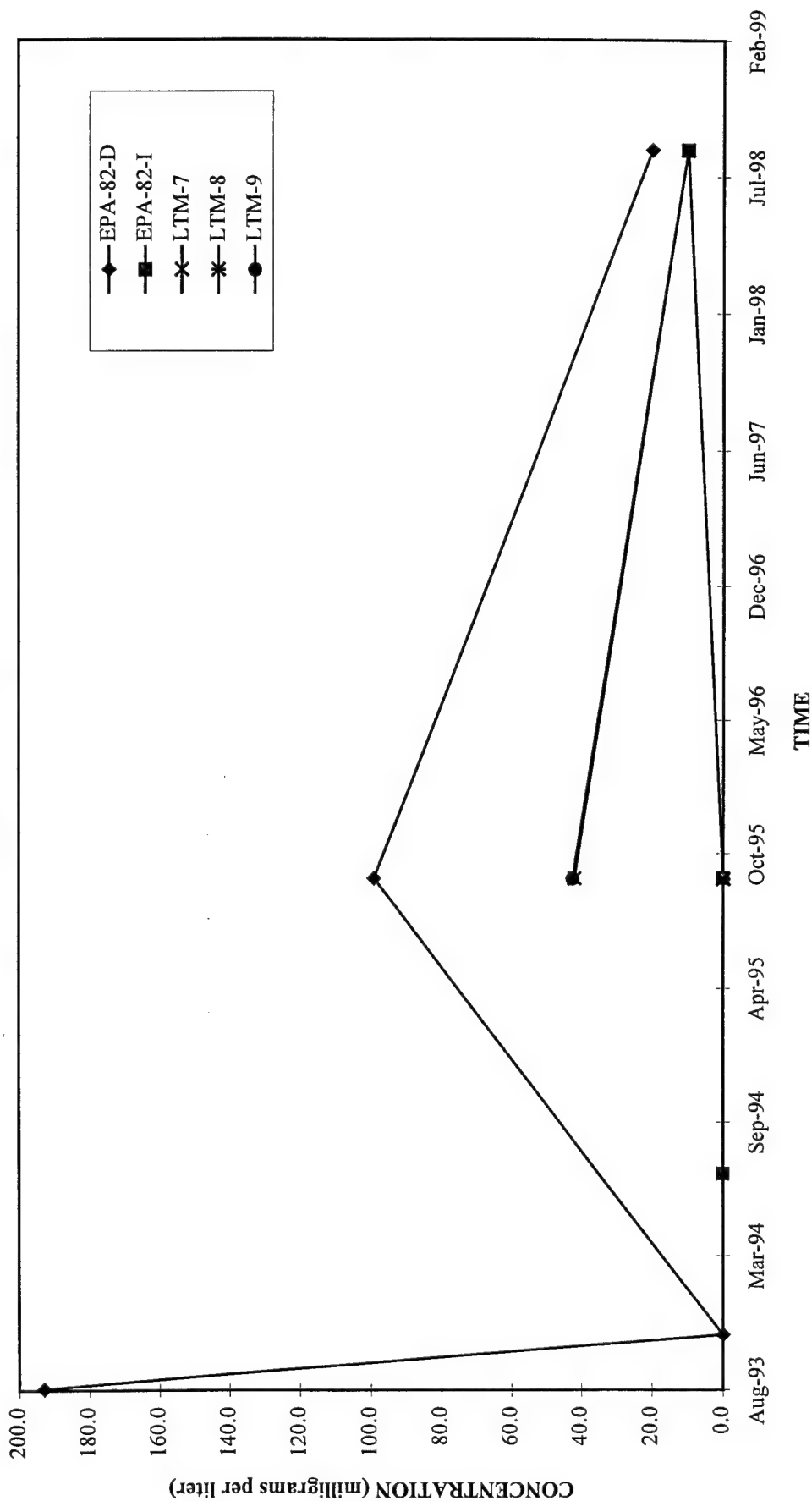
FIGURE 12

## SULFATE IN GROUNDWATER

UST Site 870  
Intrinsic Remediation EE/CA Addendum  
Hill Air Force Base, Utah

**PARSONS  
ENGINEERING SCIENCE, INC.**  
Denver, Colorado

**FIGURE 13**  
**SULFATE IN GROUNDWATER OVER TIME**  
 UST SITE 870  
 INTRINSIC REMEDIATION EE/CA ADDENDUM  
 HILL AIR FORCE BASE, UTAH



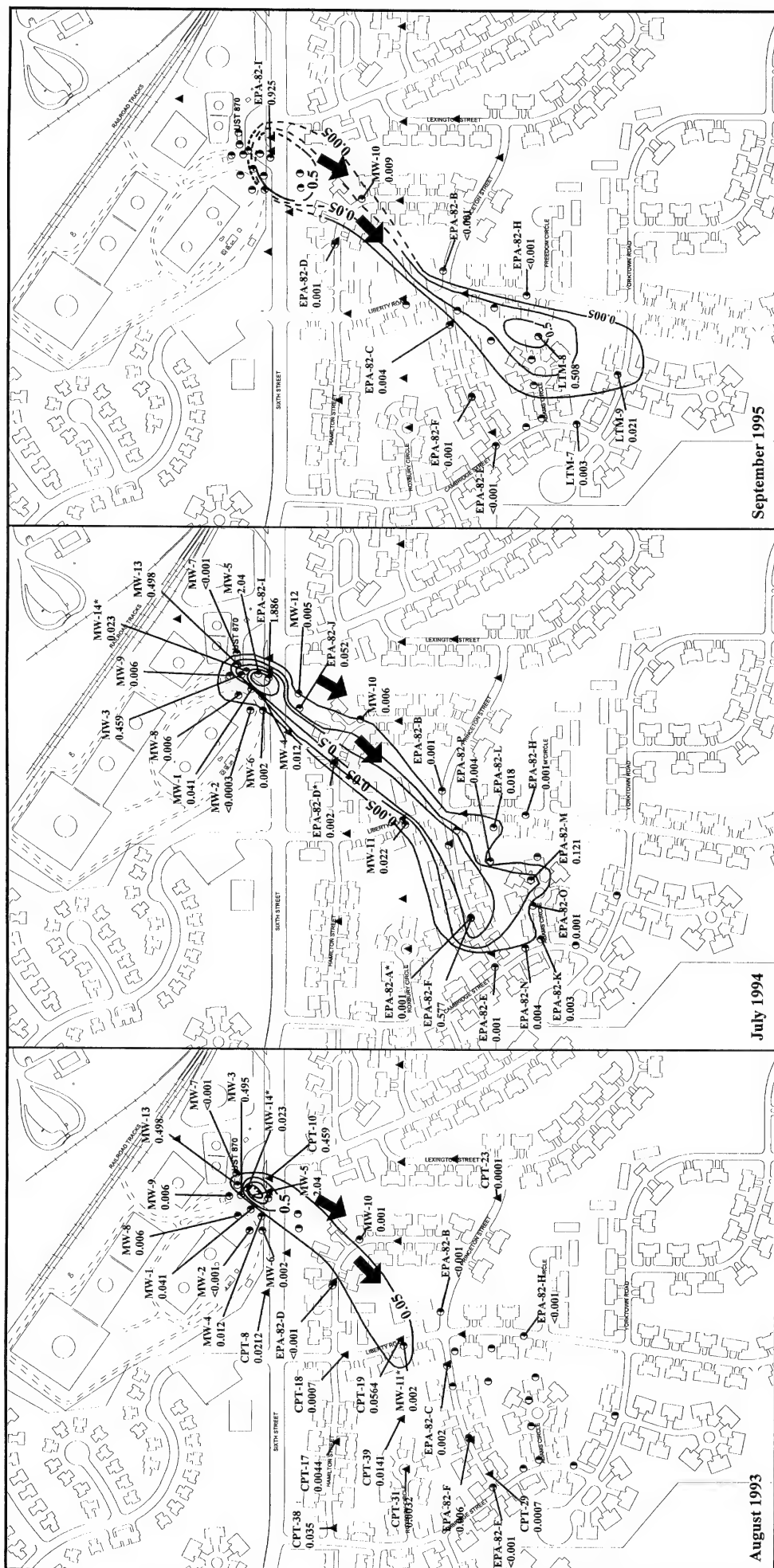
sulfate concentrations increased in EPA-82-I and LTM-8, and decreased in EPA-82-D, LTM-7, and LTM-9 between September 1995 and September 1998. However, no particular temporal or spatial trend in sulfate concentrations is apparent.

During methanogenesis, an anaerobic biodegradation process,  $\text{CO}_2$  (or acetate) is used as an electron acceptor, and methane is produced. The presence of methane in groundwater is indicative of strongly reducing conditions and is further indicative of microbial degradation of fuel hydrocarbons. As an approximation, 1.0 mg/L of methane produced by methanogenesis corresponds to the degradation of approximately 1.3 mg/L of BTEX (Weidemeier *et al*, 1994). Methane concentrations in groundwater were not measured in 1998. However, methane concentration contour maps for 1993, 1994, and 1995 are presented on Figure 14. Data that were believed to be unrepresentative of the contaminated zone (e.g., well screen not appropriately located) were not used for contouring. These values are identified on Figure 14 with an asterisk. Although the methane plumes presented on Figure 14 mimic the areal extents of the BTEX plumes, the concentrations of methane detected are generally low, suggesting that methanogenesis is not as significant a factor in biodegradation of BTEX at the site as some of the other processes described above. However, methane concentrations near source area well EPA-82-I have been significantly elevated (1.886 mg/L in July 1994 and 0.925 mg/L in September 1995), suggesting that methanogenesis is occurring to a greater degree in this area.

Alkalinity is a measure of the ability of water to buffer changes in pH. Alkalinity can be used as an indicator of biodegradation of BTEX. Biodegradation of BTEX produces carbon dioxide which, when mixed with water in the proper conditions, produces carbonic acid. In aquifers that have carbonate minerals as part of the matrix, carbonic acid dissolves these minerals, increasing the alkalinity of the groundwater. Therefore, an increase in alkalinity can be observed in areas of active intrinsic bioremediation of BTEX. Total alkalinity [(measured as calcium carbonate ( $\text{CaCO}_3$ ))] of groundwater samples collected at the site from August 1993 to September 1998 is summarized in Table 4. Alkalinity contour maps for 1993, 1994, 1995, and 1998 are shown on Figure 15. Data that were believed to be unrepresentative of the contaminated zone (e.g., well screen not appropriately located) were not used for contouring. These values are identified on Figure 15 with an asterisk. Comparison of Figures 15 and 3 demonstrates that the areas with the highest total BTEX concentrations also have elevated alkalinity concentrations. The correlation of elevated alkalinity and BTEX concentrations provides strong evidence that acids are being produced and buffered through the anaerobic biodegradation of BTEX. Figure 16 shows the increase in alkalinity of groundwater at the site over time. Of the five wells with available alkalinity data for both September 1998 and September 1995, all indicate an increase in alkalinity over time, further supporting the continued occurrence of BTEX biodegradation at the site.

### 3.0 CONCLUSIONS AND RECOMMENDATIONS

Results from the long-term groundwater monitoring conducted during September 1998 continue to support the occurrence of intrinsic bioremediation at the UST 870 site. This is evidenced by the decrease in total dissolved BTEX concentrations in the source area, the apparent stabilization of the BTEX plume, and the distributions of electron acceptors/metabolic byproducts that are involved in biologically mediated redox reactions.



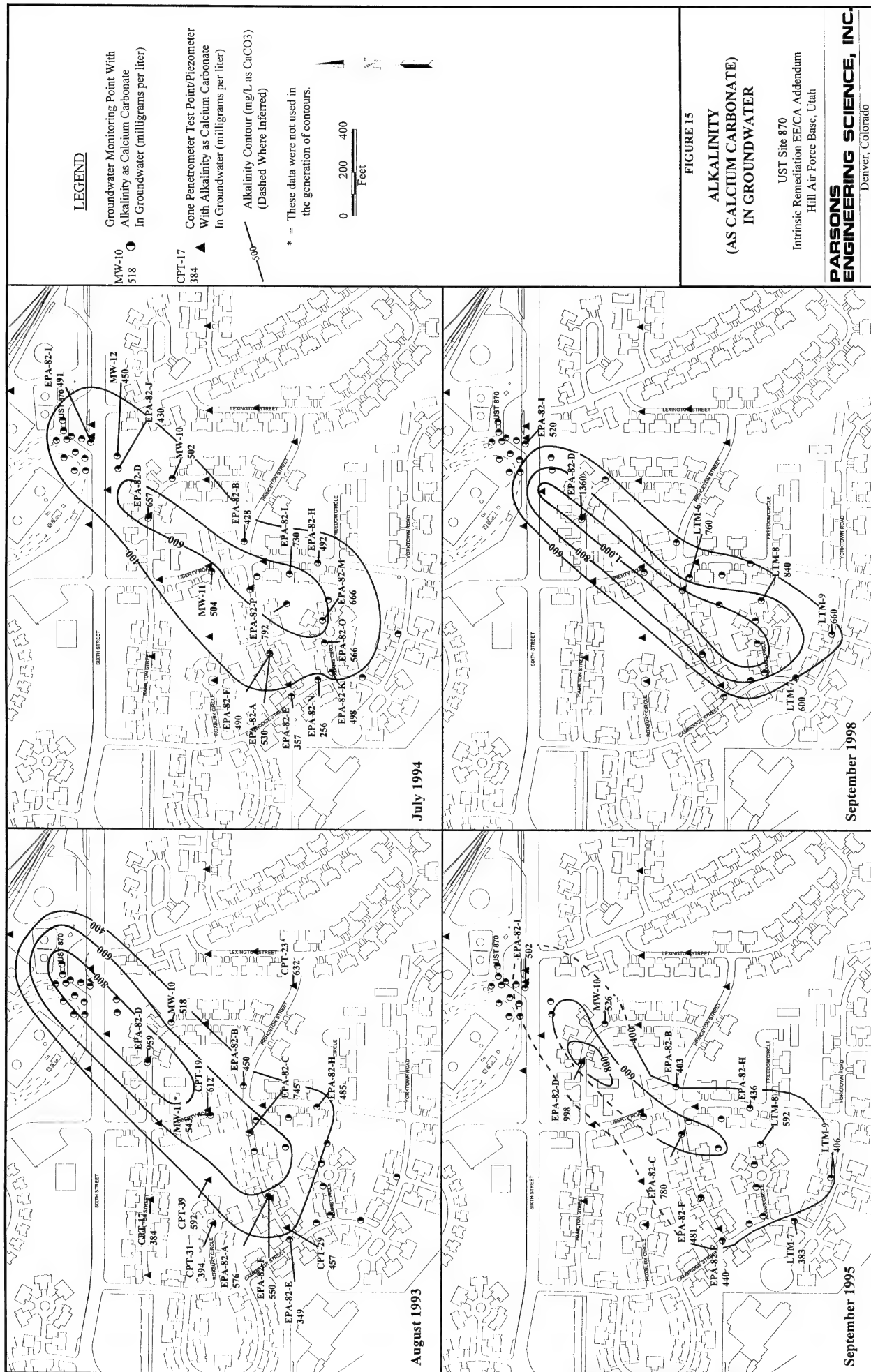
**FIGURE 14**

# METHANE IN GROUNDWATER

UST Site 870  
Intrinsic Remediation EE/CA Addendum  
Hill Air Force Base, Utah

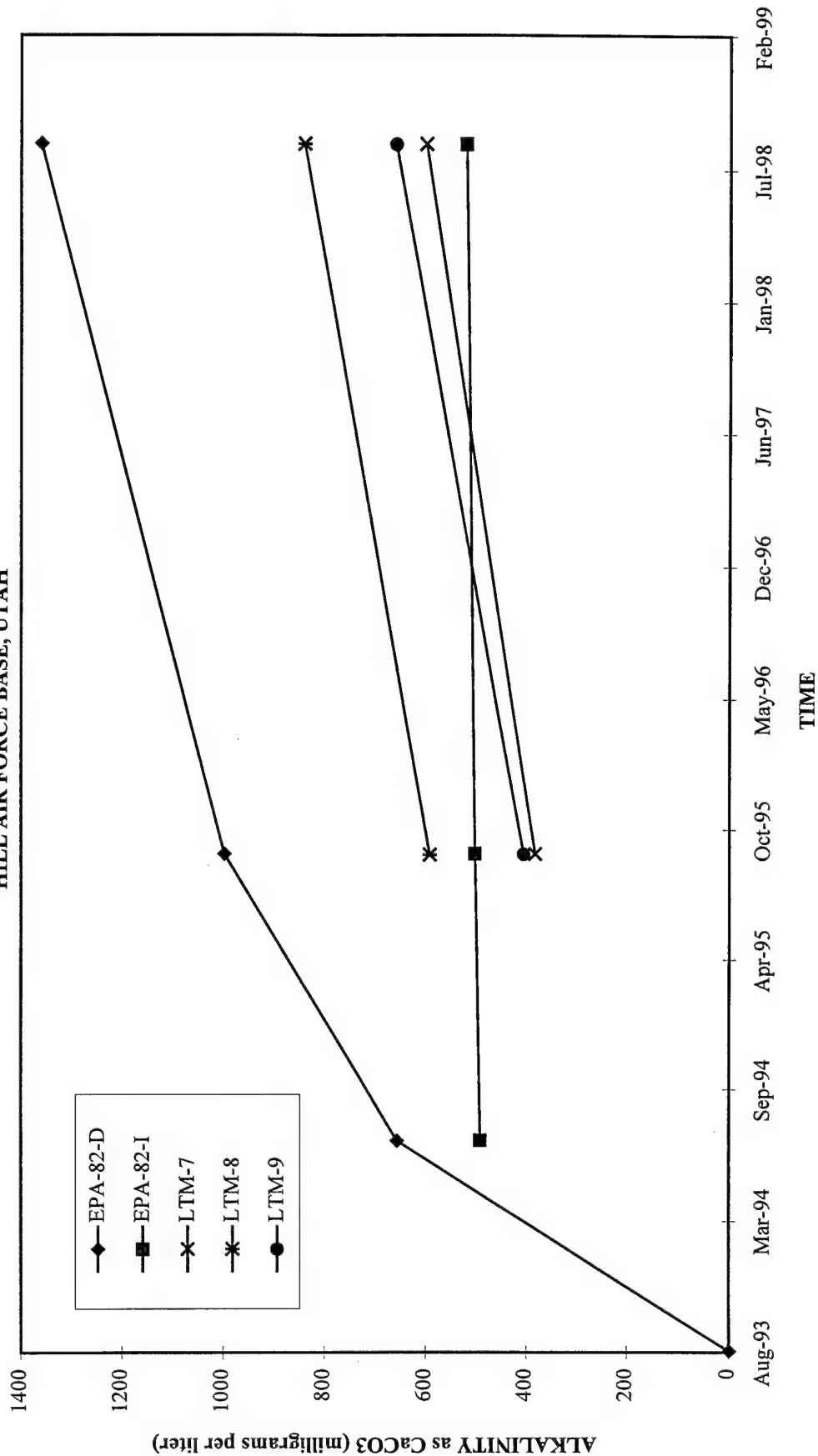
**PARSONS  
ENGINEERING SCIENCE, INC.**  
Denver, Colorado







**FIGURE 16**  
**GROUNDWATER ALKALINITY OVER TIME**  
 UST SITE 870  
 INTRINSIC REMEDIATION EE/CA ADDENDUM  
 HILL AIR FORCE BASE, UTAH



The BTEX plume is still largely anaerobic, and anaerobic biodegradation processes (e.g., iron reduction, sulfate reduction) appear to be the predominant destructive attenuation mechanisms. Methanogenesis appears to be significant in the source area and less significant in more downgradient areas. The September 1998 ORP measurements suggest the presence of a more oxidizing groundwater environment, suggesting that the processes of sulfate reduction and methanogenesis, which both require a highly reducing environment, were less predominant in September 1998 than in September 1995. However, additional ORP data is required to assess whether this is a long-term trend or representative of natural seasonal variability.

As predicted by all three Bioplume II simulations included in the EE/CA (Parsons ES, 1995), the leading edge of the dissolved BTEX plume appears to have expanded between 1993 and 1995, and appears to have achieved a steady-state condition since 1995. However, BTEX concentrations within the plume are generally decreasing, and this decrease should eventually cause the plume extent to diminish.

Continued LTM is recommended to confirm BTEX plume stability and to establish whether Bioplume II model predictions continue to match the observed BTEX plume fate and transport. The extent of the dissolved BTEX plume, approximately 1,950 feet long and 800 feet wide, is relatively large compared to typical fuel hydrocarbon plumes. The number of sampling locations monitored in September 1998 (six) is only marginally adequate for determining plume concentrations, background conditions, and establishing plume stability for a plume of this size. Therefore, additional sampling points should be considered for future long-term monitoring events.

#### 4.0 REFERENCES

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- Lovley, D.R., Phillips, E.J.P., and Lonergan, D.J., 1991, Enzymatic versus nonenzymatic mechanisms for Fe(III) reduction in aquatic sediments: *Environmental Science and Technology*, v. 26, no. 6, p. 1062 - 1067.
- Parsons Engineering Science, Inc., 1995, Intrinsic Remediation Engineering Evaluation/Cost Analysis for UST Site 870, Hill Air Force Base, Ogden, Utah. Prepared for Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks AFB, Texas, US Air Force Contract F41624-92-D-8036, June.
- Weidemeier, T.H., Wilson, J.T., Kampbell, D.H., and Miller, R.N., 1994, Proposed Air Force Guidelines for Successfully Supporting the Intrinsic Remediation (Natural Attenuation) Option at Fuel Hydrocarbon-Contaminated Sites. Presented at the 1994 Outdoor Action Conference, May 23-25, 1994, Minneapolis, Minnesota.
- Wilson, B.H., Wilson, J.T., Kampbell, D.H., Bledsoe, B.E., and Armstrong, J.M., 1990, Biotransformation of Monoaromatic and Chlorinated Hydrocarbons at an Aviation Gasoline Spill Site. *Geomicrobiology Journal*, 8:225-240.

**APPENDIX A**  
**ANALYTICAL DATA**

# MANAGEMENT TECHNOLOGY

Ref: 98-MB11  
Contract# 68-C-98-138  
September 16, 1998

Dr. Don Kampbell  
National Risk Management Research Laboratory  
Subsurface Protection and Remediation Division  
U.S. Environmental Protection Agency  
P.O. Box 1198  
Ada, OK 74820

THRU: Dr. D. Fine *to line*

Dear Don:

Please find attached the analytical results for Hill AFB, UT, Service Request SF-0-13 requesting the analysis of monitoring well samples to be analyzed for MTBE, benzene, toluene, ethylbenzene, p-, m-, and o-xylene, 1,3,5-, 1,2,4-, and 1,2,3-trimethylbenzene, and total fuel carbon. We received your 6 samples September 4, 1998 in capped, lead lined 40 mL VOA vials. The samples were analyzed on September 15, 1998. Samples were stored at 4°C until analyzed. Please note: samples LTM-3, LTM-6 and LTM-8 were diluted 1:10 with boiled milli-Q water. All samples were acquired and processed using the Millennium data system. A 5 point (1-1000 ppb) external calibration curve was used to determine the concentration for all compounds.

RSKSOP-133 "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column/Dual Detector Gas Chromatography in Ground Water Samples" was used for these analyses. Autosampling was performed using a Dynatech-Precision autosampler in-line with a Tekmar LSC 2000 sample concentrator.

Sincerely,

*Mark Blankenship*  
Mark Blankenship

xc: R.L. Cosby  
G.B. Smith  
J.L. Seeley *JS*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive  
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

| SAMPLE NAME            | MTBE | BENZENE | TOLUENE | ETHYLBENZENE | P-XYLENE | m-XYLENE | O-XYLENE | 1,3,5-TMB | 1,2,4-TMB | 1,2,3-TMB | FUEL CARBON |
|------------------------|------|---------|---------|--------------|----------|----------|----------|-----------|-----------|-----------|-------------|
| QC, OBSERVED, 20 PPB   | 19.0 | 19.4    | 19.1    | 18.3         | 19.3     | 19.0     | 19.1     | 19.2      | 19.5      | 18.2      | N/A         |
| QC, TRUE VALUE, 20 PPB | 20.0 | 20.0    | 20.0    | 20.0         | 20.0     | 20.0     | 20.0     | 20.0      | 20.0      | 20.0      | N/A         |
| 100 PPB STD            | 87.7 | 88.5    | 88.3    | 89.6         | 89.8     | 88.5     | 88.0     | 90.1      | 88.7      | 100.6     | N/A         |
| GC LAB BLANK           | ND   | ND      | ND      | ND           | ND       | ND       | ND       | ND        | ND        | ND        | N/A         |
| LTM-4/EPA 82 D         | 4.0  | 3.4     | 2.5     | 47.4         | 55.9     | 94.5     | 30.2     | 97.2      | 182.3     | 77.3      | 1537        |
| LTM-7                  | ND   | ND      | ND      | BLQ          | 1.2      | 2.2      | BLQ      | ND        | 1.5       | BLQ       | 7.6         |
| LTM-9                  | ND   | ND      | ND      | 1.5          | 13.8     | 5.3      | 8.7      | 4.3       | 14.9      | 13.3      | 93.9        |
| LTM-3/EPA-82 I         | 3.4  | 2959    | 2363    | 608.6        | 1161     | 3473     | 1648     | 334.2     | 767.1     | 265.1     | 14848       |
| LTM-6                  | 1.8  | 19.3    | 11.4    | 346.0        | 655.6    | 1714     | 657.7    | 341.0     | 753.6     | 300.1     | 5460        |
| LTM-8                  | 3.4  | 7.9     | 7.5     | 283.0        | 589.3    | 1516     | 738.2    | 337.3     | 786.2     | 308.6     | 5307        |
| 100 PPB STD            | 92.0 | 94.0    | 97.9    | 97.5         | 97.1     | 95.2     | 98.6     | 96.5      | 94.6      | 96.8      | N/A         |

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed



Ref: 98-SH15  
Contract # 68-C-98-138

September 16, 1998

Dr. Don Kampbell  
National Risk Management Research Laboratory  
Subsurface Protection & Remediation Division  
U.S. Environmental Protection Agency  
P.O. Box 1198  
Ada, OK 74820

THRU: D.D. Fine *fine*

Dear Don:

Attached are TOC results for a set of six Hill liquids submitted September 11, 1998 under Service Request #SF-0-13. Sample analysis was begun September 16, 1998 and completed September 16, 1998 using RSKSOP-102.

Blanks, duplicates, AQC samples were analyzed along with your samples, as appropriate, for quality control. If you have any questions concerning this data, please feel free to ask me.

Sincerely,

*Sharon Hightower*  
Sharon Hightower

xc: R.L. Cosby  
G.B. Smith  
J.L. Seeley *JS*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive  
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

KAMPBELL HILL LIQUIDS SF-0-13

| SAMPLE | MG/L TOC |
|--------|----------|
| LTM-3  | 33.0     |
| LTM-4  | 52.3     |
| LTM-6  | 6.20     |
| LTM-7  | 2.82     |
| LTM-8  | 8.24     |
| LTM-9  | 6.88     |
| DUP    | 6.86     |
| WP39   | 76.8     |

WP39 std. t.v.=76.0+/-7.60





Ref: 98-AZ15  
68-C-98-138

September 10, 1998

Dr. Don Kampbell  
National Risk Management Research Laboratory  
Subsurface Protection and Remediation Division  
U.S. Environmental Protection Agency  
P.O. Box 1198  
Ada, OK 74820

THRU: D. Fine *dfine*

Dear Don:

As requested in Service Request #SF-0-13, gas analysis was performed for methane, ethylene, and ethane on samples from Hill AFB. The samples were received on September 4, 1998. The analyses were performed on September 9, 1998. These analyses were performed as per RSKSOP-194, and the calculations were done as per RSKSOP-175.

If you should have any questions, please feel free to contact me.

Sincerely,

*Amy Q. Zhao*

Amy Zhao

xc: R.L. Cosby  
G.B. Smith  
J.L. Seeley *JL*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive  
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SF-0-13 Hill AFB

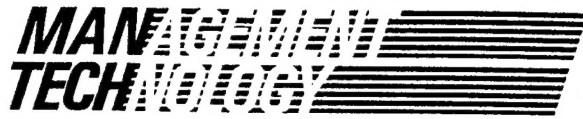
09/10/1998

| Sample                      | Methane  | Ethylene | Ethane |
|-----------------------------|----------|----------|--------|
| 100 ppm CH4                 | 102.0    | **       | **     |
| 100 ppm C2H4                | **       | 109.2    | **     |
| 100 ppm C2H6                | **       | **       | 103.0  |
| HP. Helium Blank            | **       | **       | **     |
| Lab Blank                   | **       | **       | **     |
| LTM-3                       | 0.68     | **       | 0.002  |
| LTM-4                       | 0.10     | **       | **     |
| LTM-6                       | 10.3     | **       | **     |
| LTM-7                       | **       | **       | **     |
| LTM-8                       | 0.99     | **       | **     |
| LTM-8 Lab Dup               | 0.93     | **       | **     |
| LTM-9                       | 0.80     | **       | **     |
| LTM-9 Field Dup             | 0.81     | **       | **     |
| 10PPM CH4                   | 9.6      | **       | **     |
| 10PPM C2H4                  | **       | 10.0     | **     |
| 10PPMC2H6                   | **       | **       | 10.2   |
| 1000PPM CH4                 | 1.07E+03 | **       | **     |
| Lower Limit of Quantitation | 0.001    | 0.003    | 0.002  |

Units for the standards are parts per million.

\*\* denotes None Detected.

\* denotes Below Limit of Quantitation.



September 23, 1998  
Ref: 98-LP26/lp  
Contract # 68-C-98-138

Dr. Don Kampbell  
National Risk Management Research Laboratory  
Subsurface Protection & Remediation Division  
U.S. Environmental Protection Agency  
P.O. Box 1198  
Ada, OK 74821-1198

THRU: D.D. Fine *DD*

Dear Don:

Attached are time-sensitive test results for field samples collected at Hill AFB, Utah and King Salmon, Alaska between September 1 and 9, 1998. The analysis were performed according to Service Request # SFTA-0-6. All meters and test kits used were those supplied to us on site.

If you have any questions concerning this data, please feel free to contact us.

Sincerely,

*Lynda Pennington*  
Lynda Pennington

*Mark Blankenship*  
Mark Blankenship by *AKP*

xc: R.L. Cosby  
J.L. Seeley *JLS*  
G.B. Smith

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Center, P.O. Box 1198, 919 Kerr Research Drive  
Ada, Oklahoma 74821-1198 580-436-8660 FAX 580-436-8501

| September 1-3, 1998 Hill AFB, Utah  |                           |                        |               |                         |                |               |                        |                      |                   |                            |                           |
|---|---------------------------|------------------------|---------------|-------------------------|----------------|---------------|------------------------|----------------------|-------------------|----------------------------|---------------------------|
| SAMPLE  | TOC Water Level<br>(feet) | pH                     | Redox<br>(mV) | Conductivity<br>(µS/cm) | D.O.<br>(mg/L) | Temp.<br>(°C) | Ferrous Iron<br>(mg/L) | Alkalinity<br>(mg/L) | Sulfate<br>(mg/L) | H <sub>2</sub> S<br>(mg/L) | CO <sub>2</sub><br>(mg/L) |
| LTM-3   | 16.90                     | 7.12                   | -95.3         | 875                     | 7.6            | 17.8          | 8                      | 520                  | 10                | <0.1                       | 65                        |
| LTM-4   | 22.56                     | 7.36                   | -199          | 2080                    | 0.38           | 18.5          | 2                      | 1360                 | 20                | 2.0                        | 60                        |
| LTM-6   | 23.60                     | 7.07                   | -96.5         | 1330                    | 10.4           | 18.7          | 10                     | 760                  | 5                 | <0.1                       | 60                        |
| LTM-7   | 8.58                      | 7.24                   | 150           | 1840                    | 3.45           | 17.9          | <0.1                   | 600                  | 10                | <0.1                       | 50                        |
| LTM-8   | 10.02                     | 7.14                   | -59.5         | 1520                    | 0.44           | 14.9          | 10                     | 840                  | 10                | <0.1                       | 55                        |
| LTM-9   | 11.28                     | 7.21                   | 109           | 1060                    | 1.15           | 16.1          | <0.1                   | 660                  | 10                | <0.1                       | 45                        |
| Note: LTM-4 & LTM-6 were both low-yielding wells so no hydrogen analysis was done.      |                           |                        |               |                         |                |               |                        |                      |                   |                            |                           |
| September 4-9, 1998 King Salmon, Alaska   |                           |                        |               |                         |                |               |                        |                      |                   |                            |                           |
| SAMPLE  | TOC Water Level<br>(feet) | pH                     | Redox<br>(mV) | Conductivity<br>(µS/cm) | D.O.<br>(mg/L) | Temp.<br>(°C) | Ferrous Iron<br>(mg/L) | Alkalinity<br>(mg/L) | Sulfate<br>(mg/L) | H <sub>2</sub> S<br>(mg/L) | CO <sub>2</sub><br>(mg/L) |
| ESMW-1A   | 16.8                      | 5.0                    | -90           | 145                     | 0.85           | 6.2           | 5                      | 100                  | 5                 | <0.1                       | 50                        |
| ESMW-1B   | 16.8                      | 5.0                    | 38            | 135                     | 2.0            | 5.8           | 0.1                    | 80                   | 5                 | <0.1                       | 20                        |
| ESMW-2A   | 18.2                      | 5.0                    | 169           | 126                     | 6.7            | 5.6           | 0.1                    | 60                   | <5                | <0.1                       | 20                        |
| ESMW-4A   | 16.1                      | 4.9                    | 385           | 88.8                    | 10             | 5.0           | 0.1                    | 45                   | <5                | <0.1                       | 20                        |
| MW-95   | 15.1                      | 5.2                    | -89           | 185                     | 0.9            | 6.8           | 3                      | 85                   | 10                | <0.1                       | 30                        |
| ESMW-5A   | 6.2                       | 5.2                    | 44            | 221                     | 1.28           | 7.3           | 0.8                    | 110                  | 5                 | <0.1                       | 22                        |
| ESMW-3A   | 16.9                      | 4.9                    | 132           | 102                     | 3.2            | 5.8           | 0.1                    | 50                   | 5                 | <0.1                       | 25                        |
| MW-51   | 11.5                      | 5.1                    | -48           | 400                     | 0.7            | 5.2           | 8                      | 195                  | 5                 | <0.1                       | 96                        |
| MW-500  | 19.1                      | 5.3                    | -71           | 380                     | 1.4            | 4.5           | 20                     | 220                  | 5                 | <0.1                       | 70                        |
| MW-501  | 14.2                      | "pumped dry" - no data |               |                         |                |               |                        |                      |                   |                            |                           |
| MW-88   | 14.4                      | 5.0                    | 24            | 276                     | 2.0            | 6.0           | 5                      | 120                  | <5                | <0.1                       | 45                        |
| WP-1A   | 4.8                       | 5.1                    | -69           | 355                     | 0.7            | 3.8           | 40                     | 60                   | <5                | <0.1                       | 85                        |
| WP-1B   | 5.4                       | 5.0                    | 22            | 111                     | 7.4            | 6.7           | 0.1                    | 200                  | 10                | <0.1                       | 10                        |
| ESMW-8A   | 12.3                      | 5.2                    | -40           | 540                     | 0.8            | 7.0           | 30                     | 280                  | <5                | <0.1                       | 75                        |
| ESMW-8B   | 10.7                      | 5.0                    | -11           | 108                     | 0.9            | 5.8           | 0.1                    | 60                   | <5                | <0.1                       | 15                        |
| ESMW-15A  | 16.1                      | 5.3                    | -23           | 393                     | 0.6            | 4.8           | >50                    | 200                  | <5                | <0.1                       | ***                       |
| ESMW-15B  | 16.1                      | 5.5                    | -3            | 430                     | 2.0            | 5.0           | 1.5                    | 220                  | <5                | <0.1                       | 1.5                       |
| *** = couldn't determine an endpoint for CO2 due to high concentration of ferrous iron. |                           |                        |               |                         |                |               |                        |                      |                   |                            |                           |